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(12) **United States Patent**
Doughty

(10) **Patent No.:** **US 9,224,568 B2**
(45) **Date of Patent:** **Dec. 29, 2015**

(54) **ARC TUBE DEVICE AND STEM STRUCTURE FOR ELECTRODELESS PLASMA LAMP**

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(73) Assignee: **TOPANGA USA**, Canoga Park, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 89 days.

(21) Appl. No.: **14/106,674**

(22) Filed: **Dec. 13, 2013**

(65) **Prior Publication Data**

US 2014/0187116 A1 Jul. 3, 2014

Related U.S. Application Data

(62) Division of application No. 13/004,868, filed on Jan. 11, 2011, now Pat. No. 8,629,616.

(51) **Int. Cl.**

H01J 9/34	(2006.01)
H01J 61/12	(2006.01)
H01J 61/33	(2006.01)
H01J 65/04	(2006.01)
H01J 9/385	(2006.01)
H01J 9/395	(2006.01)
H01J 9/40	(2006.01)
H01J 9/42	(2006.01)

(52) **U.S. Cl.**

CPC . ***H01J 9/34*** (2013.01); ***H01J 9/385*** (2013.01); ***H01J 9/395*** (2013.01); ***H01J 9/40*** (2013.01); ***H01J 9/42*** (2013.01); ***H01J 61/12*** (2013.01); ***H01J 61/33*** (2013.01); ***H01J 65/042*** (2013.01)

(58) **Field of Classification Search**

CPC H01J 9/34; H01J 9/32; H01J 9/323; H01J 9/326

See application file for complete search history.

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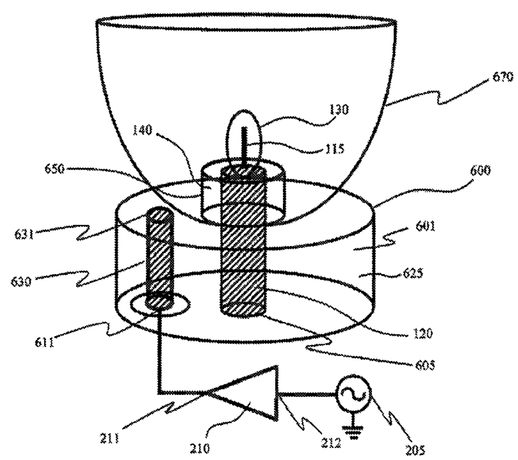
Primary Examiner — Anne Hines

(74) *Attorney, Agent, or Firm* — Kilpatrick Townsend and Stockton LLP

(57) **ABSTRACT**

A plasma lamp apparatus. The apparatus has an arc tube structure having an inner region and an outer region in one or more embodiments. The arc tube structure has a first end comprising an associated first end diameter and a second end comprising a second end diameter according to a specific embodiment. The apparatus also has a center region provided between the first end and the second end in one or more embodiments. The center region has a center diameter, which is less than a first end diameter and/or a second end diameter.

55 Claims, 37 Drawing Sheets



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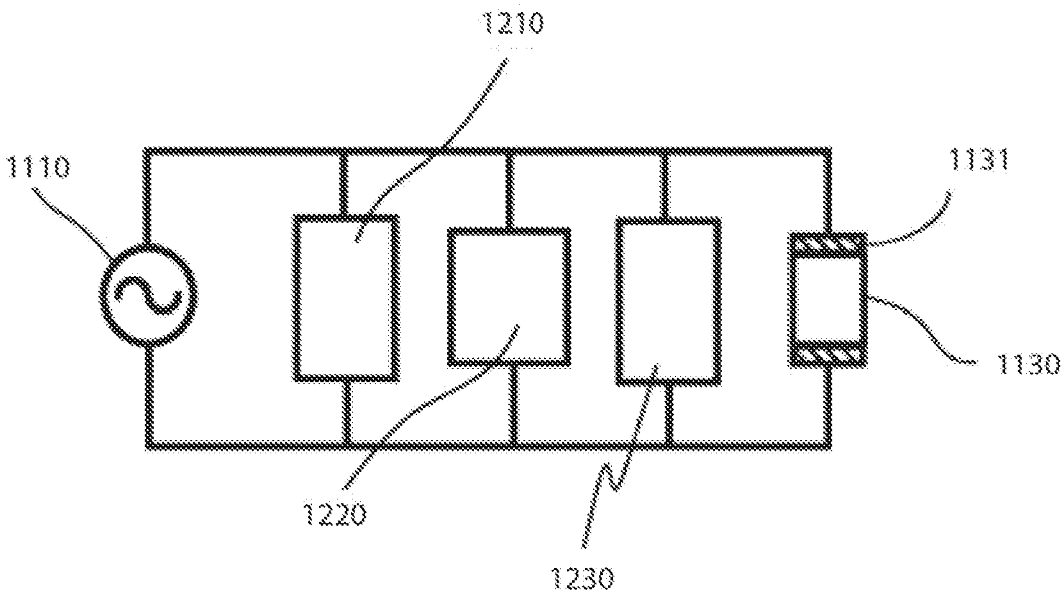


FIG. 1A

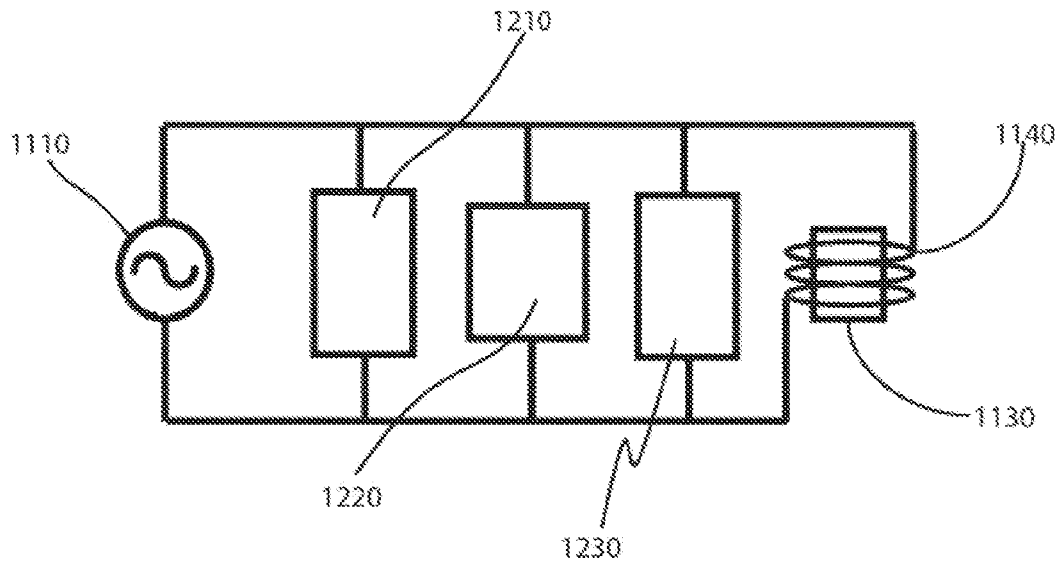
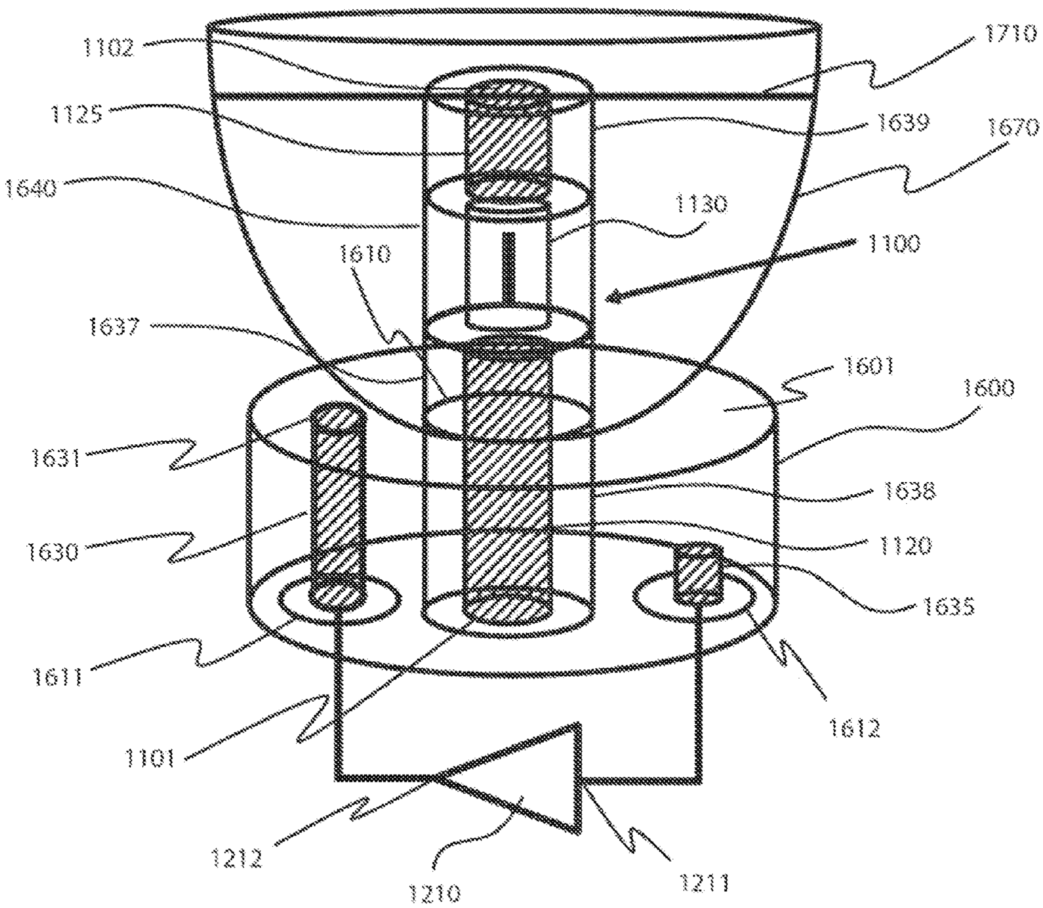


FIG. 1B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1611
1612
1101
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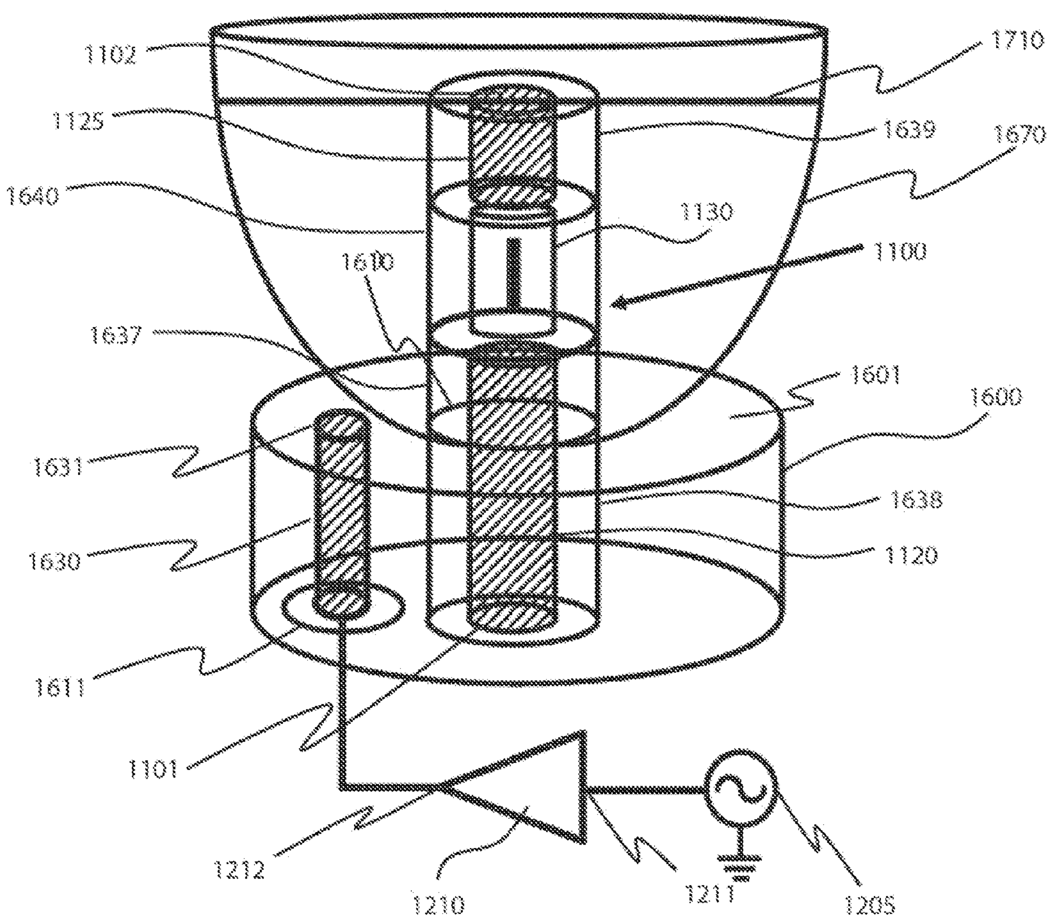
1210
1211

FIG. 2A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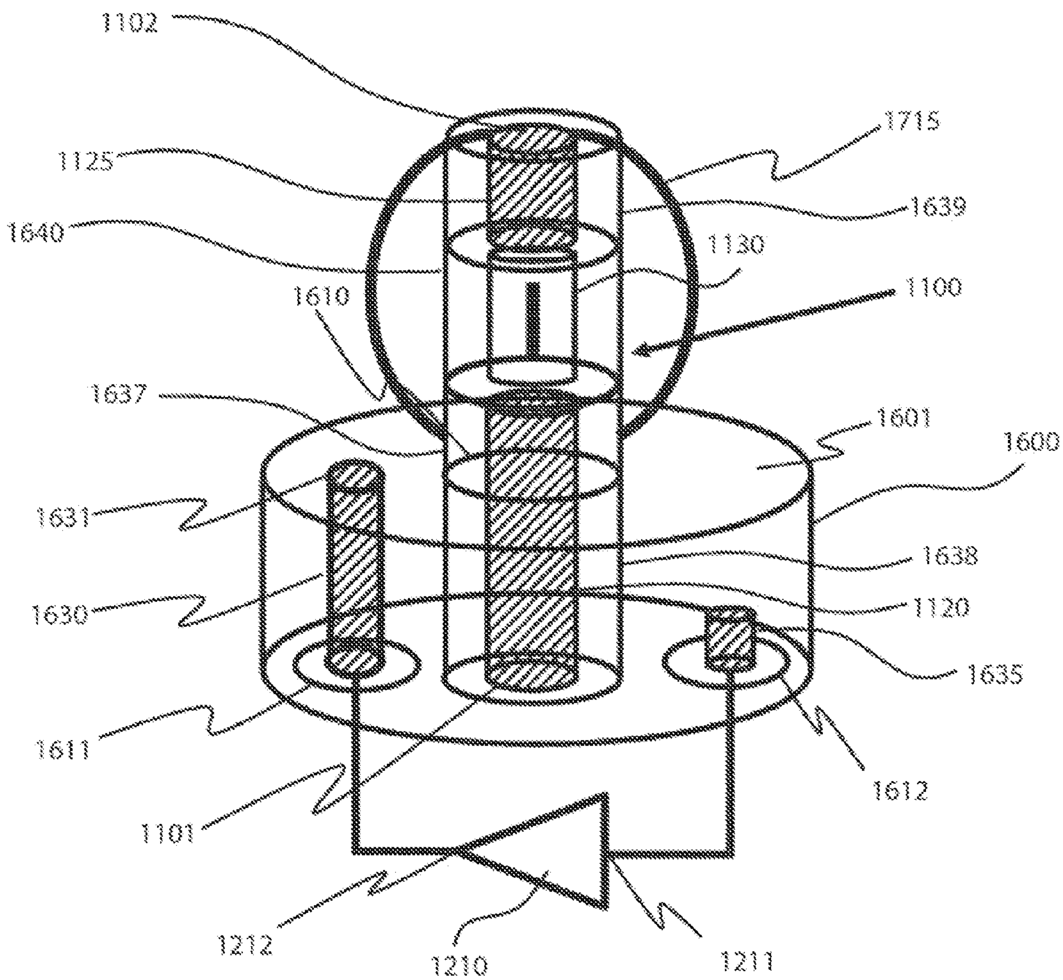
1212
1210
1211
1205

FIG. 2B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1211

FIG. 2C

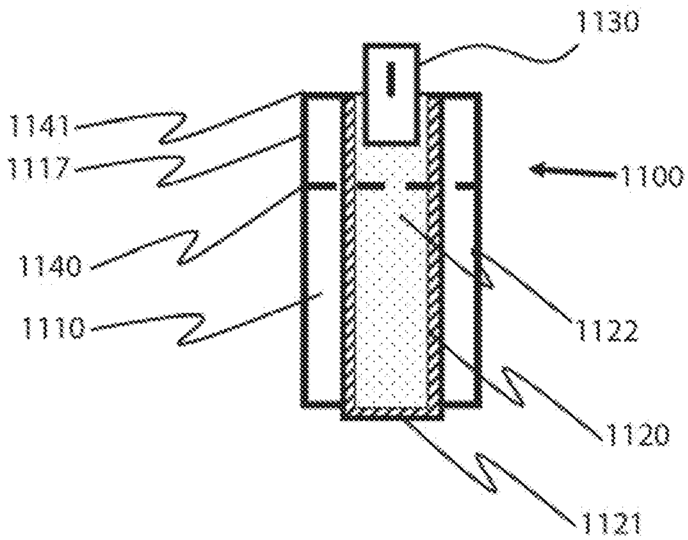
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FIG. 3A

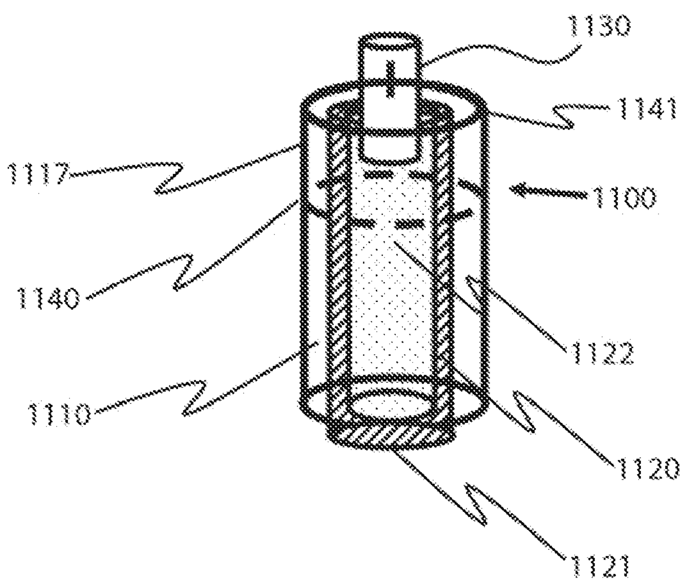
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FIG. 3B

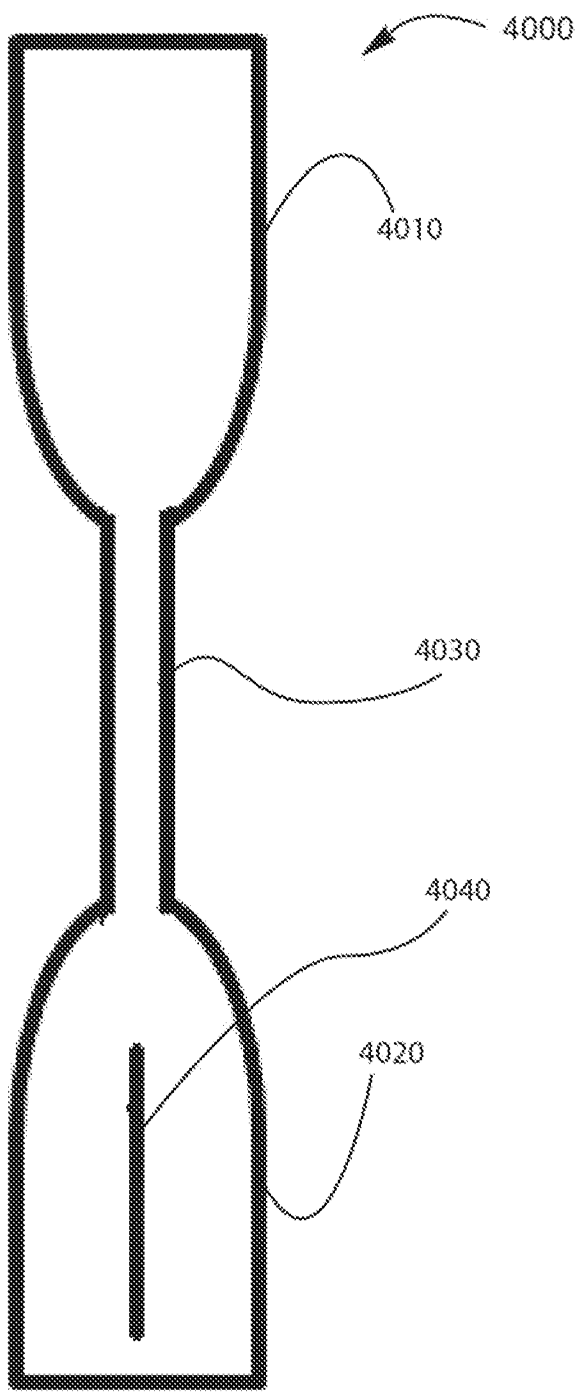


FIG. 4A

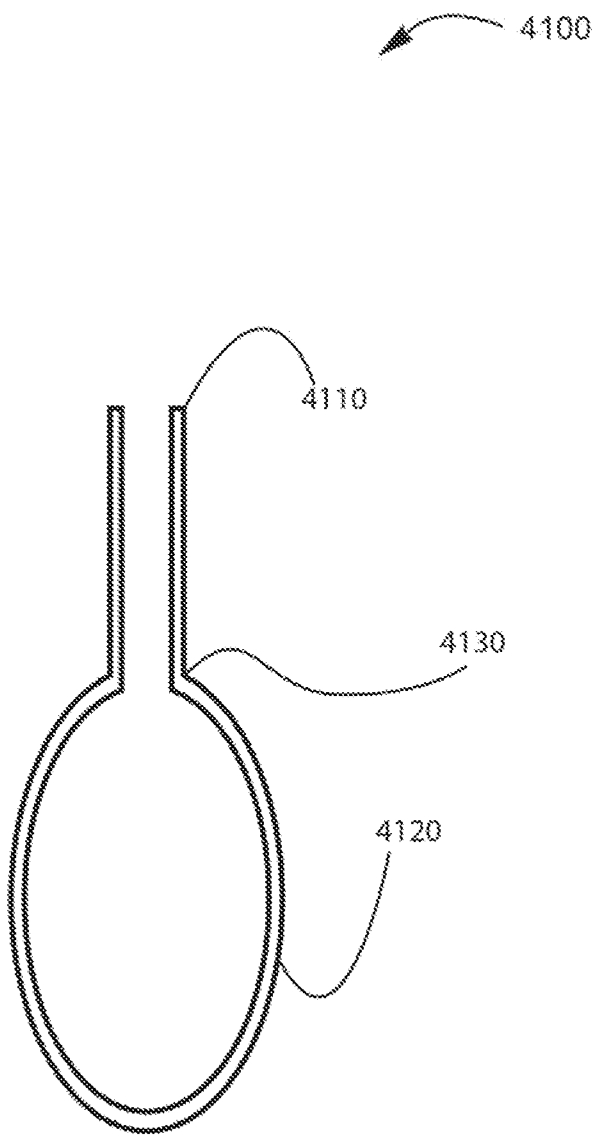


FIG. 4B

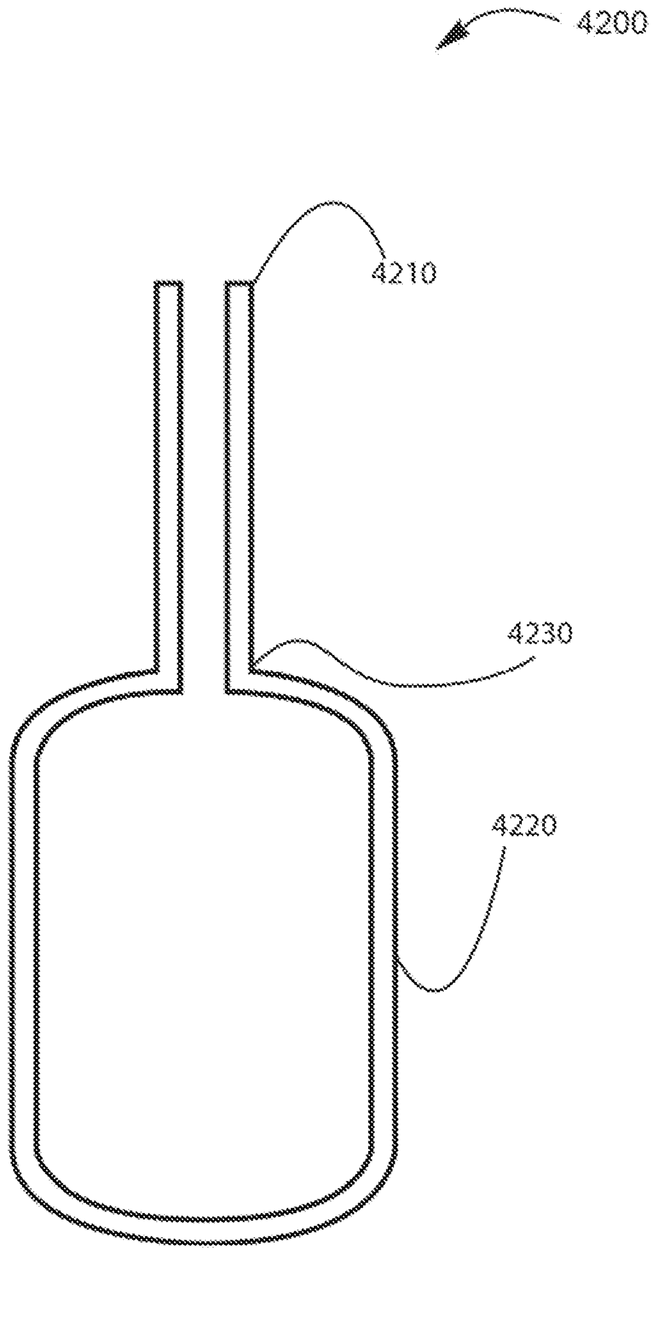


FIG. 4C

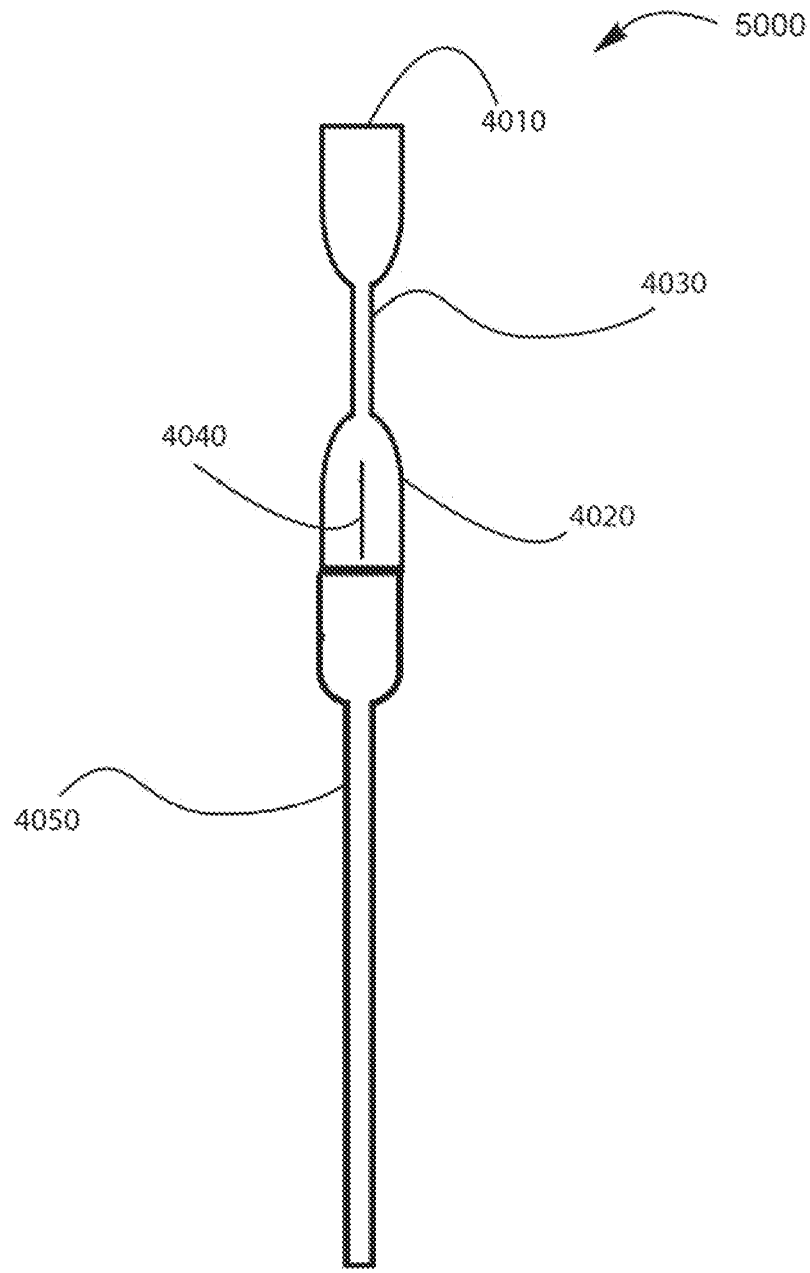


FIG. 5A

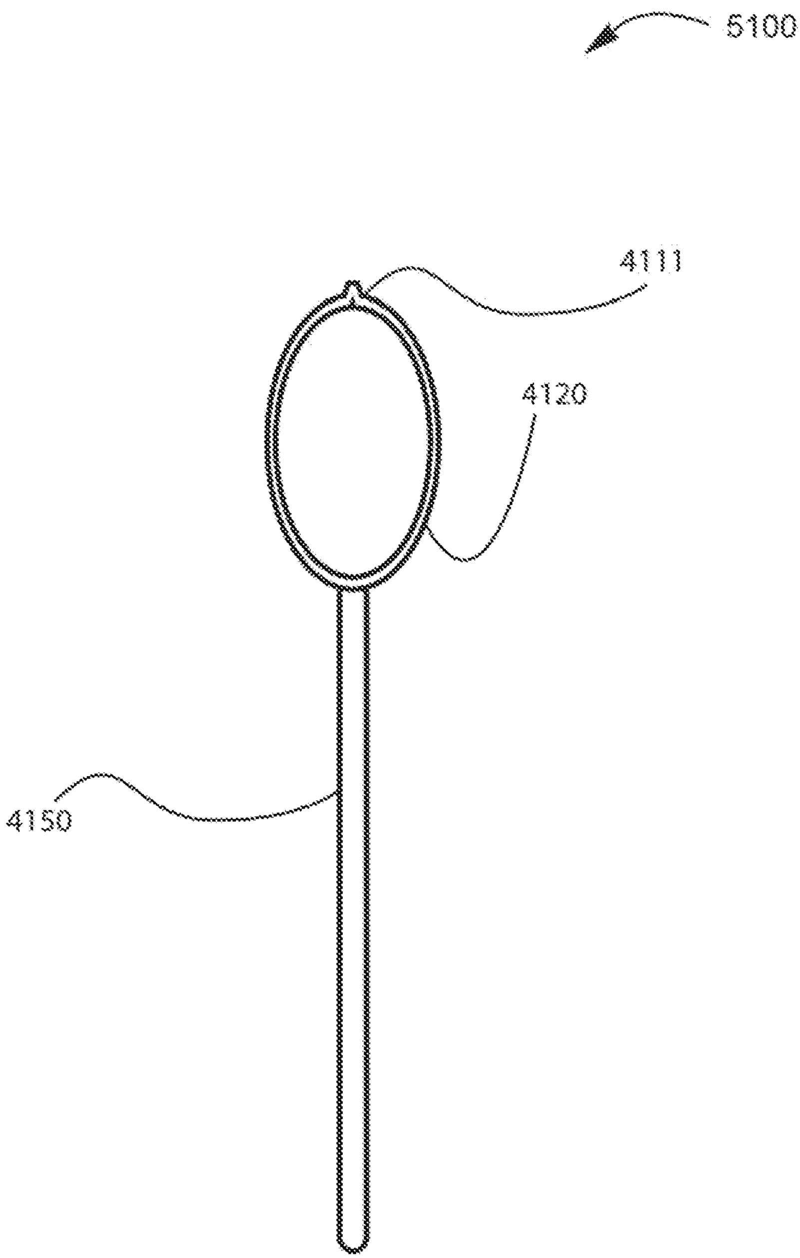


FIG. 5B

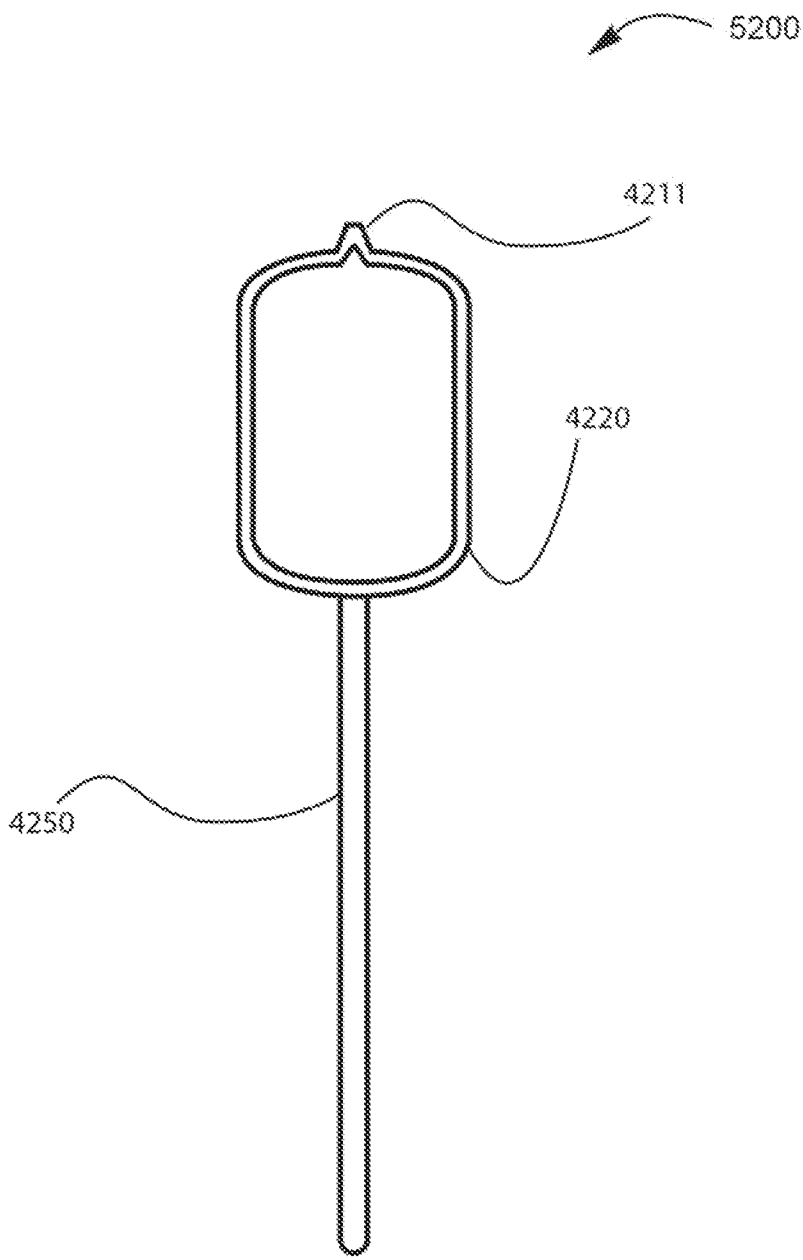


FIG. 5C

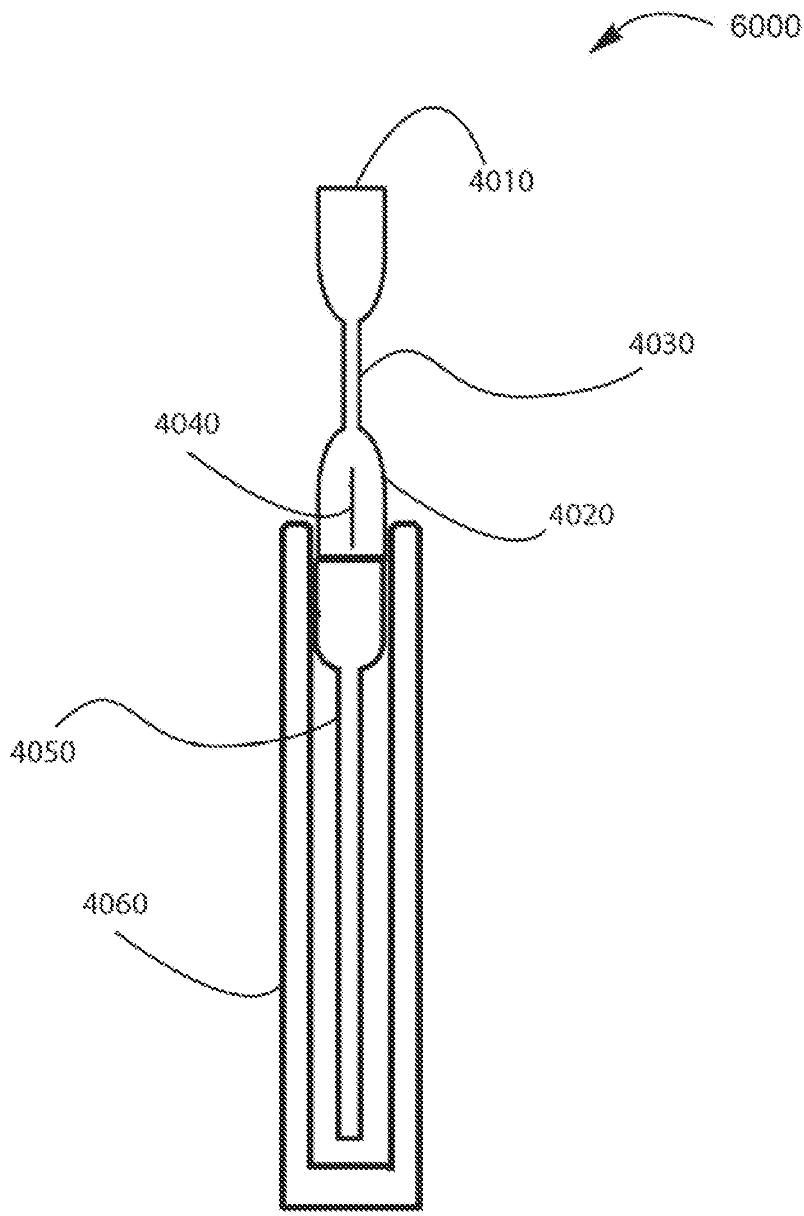


FIG. 6A

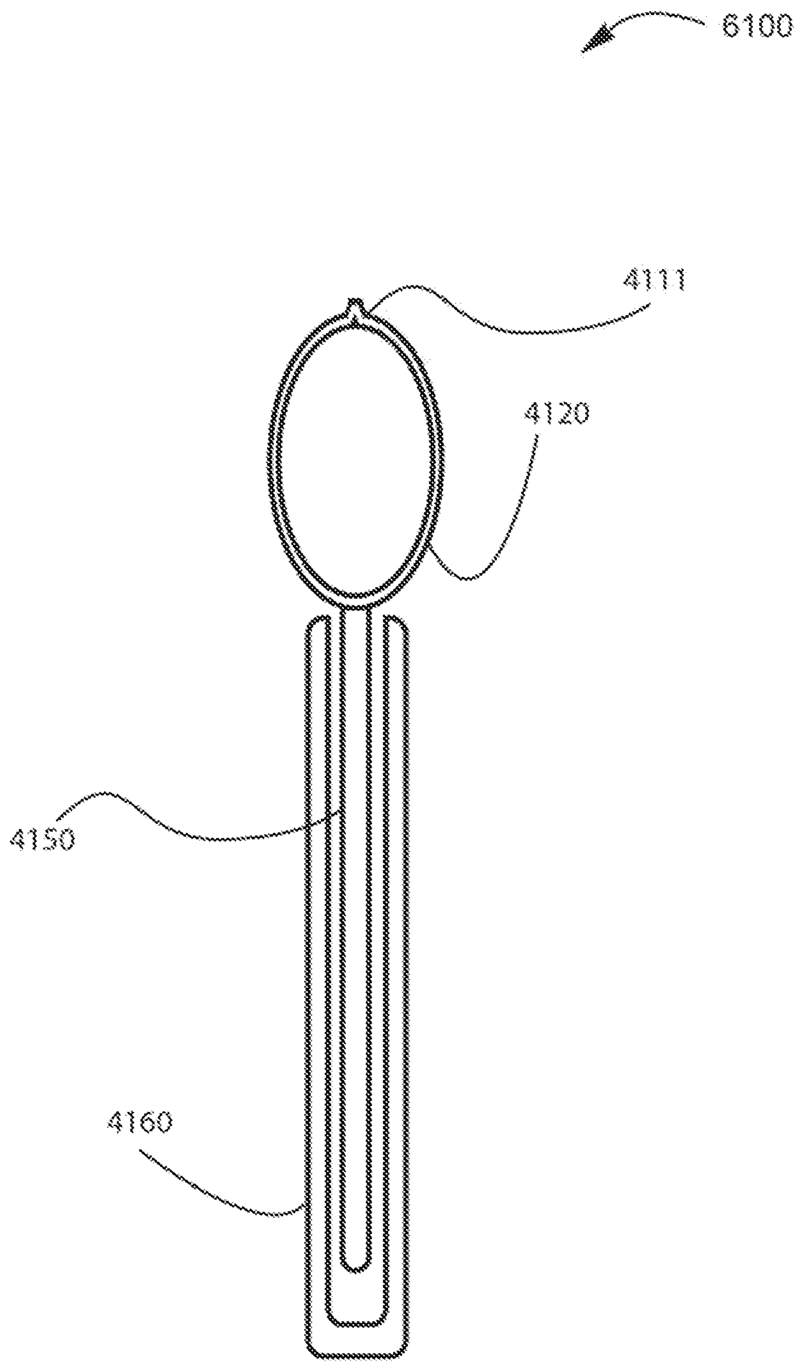


FIG. 6B

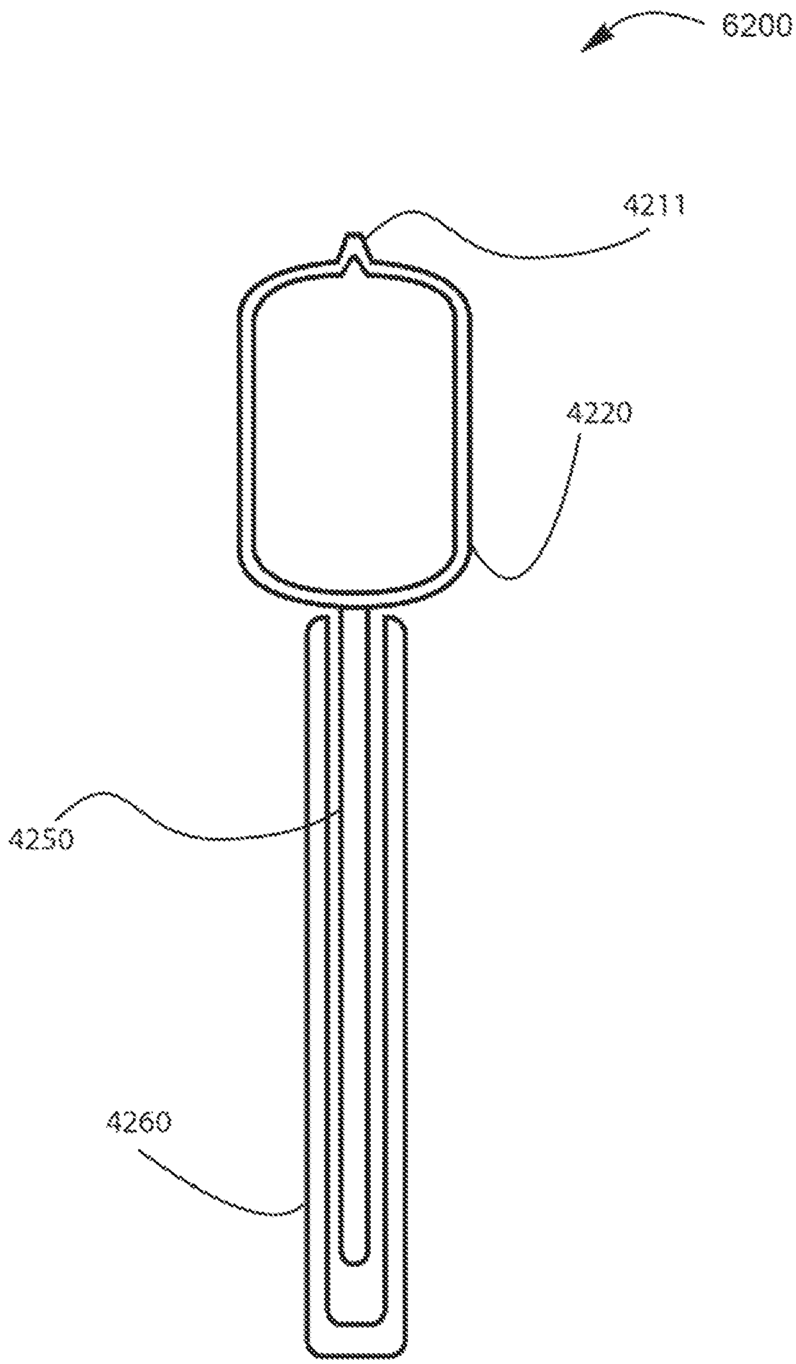


FIG. 6C

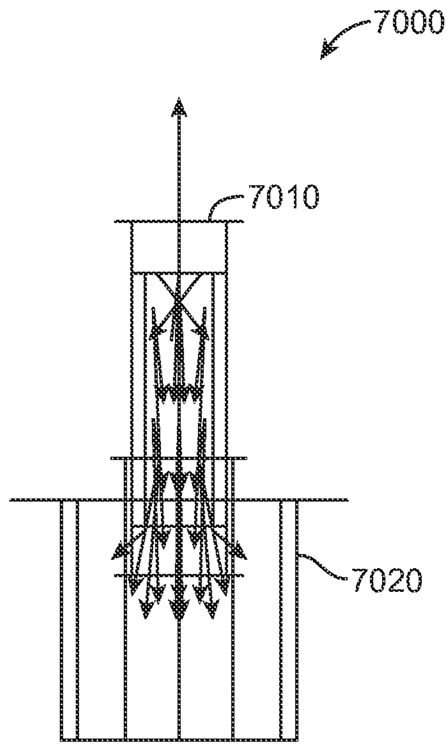


FIG. 7

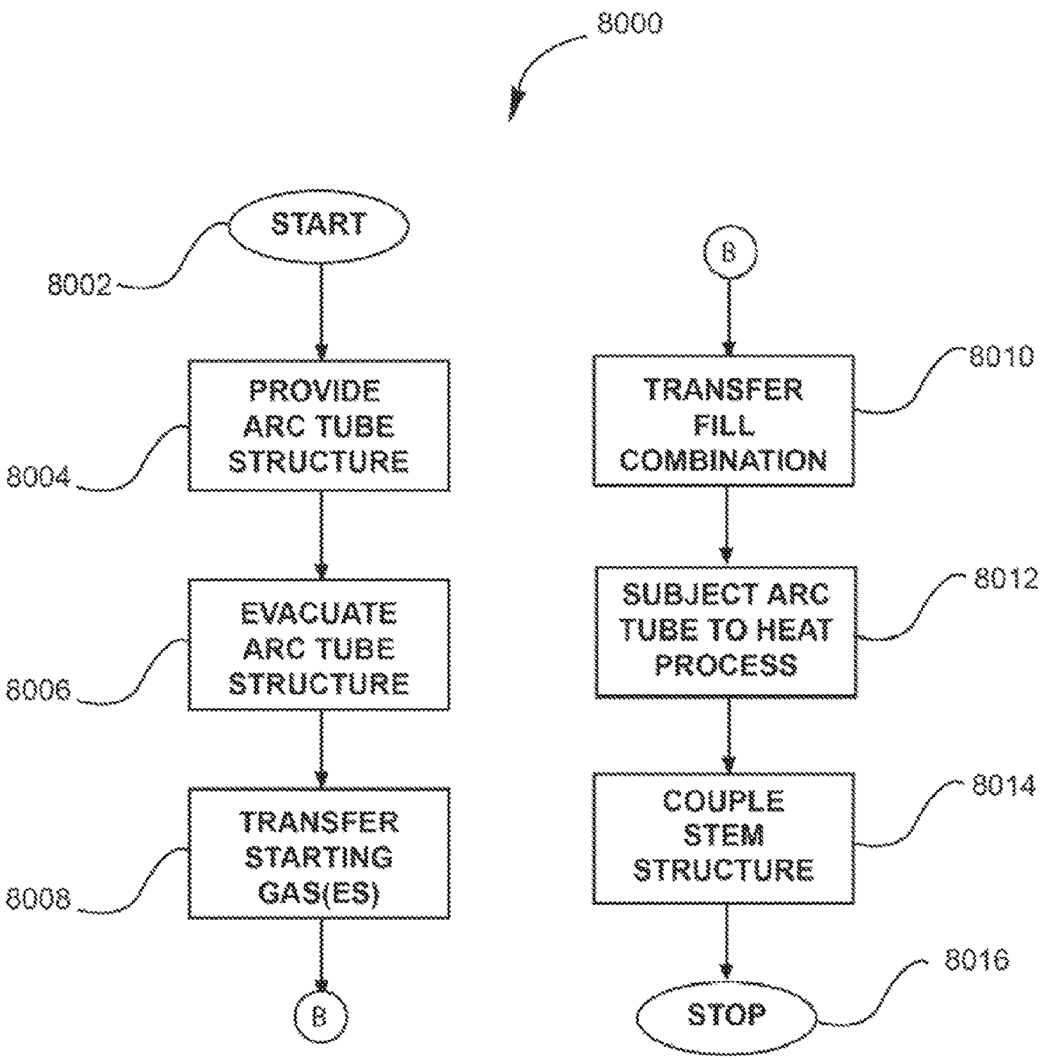

8000
START
8002
PROVIDE ARC TUBE STRUCTURE
8004
EVACUATE ARC TUBE STRUCTURE
8006
TRANSFER STARTING GAS(ES)
8008
B
B
TRANSFER FILL COMBINATION
8010
SUBJECT ARC TUBE TO HEAT PROCESS
8012
COUPLE STEM STRUCTURE
8014
STOP
8016

FIG. 8

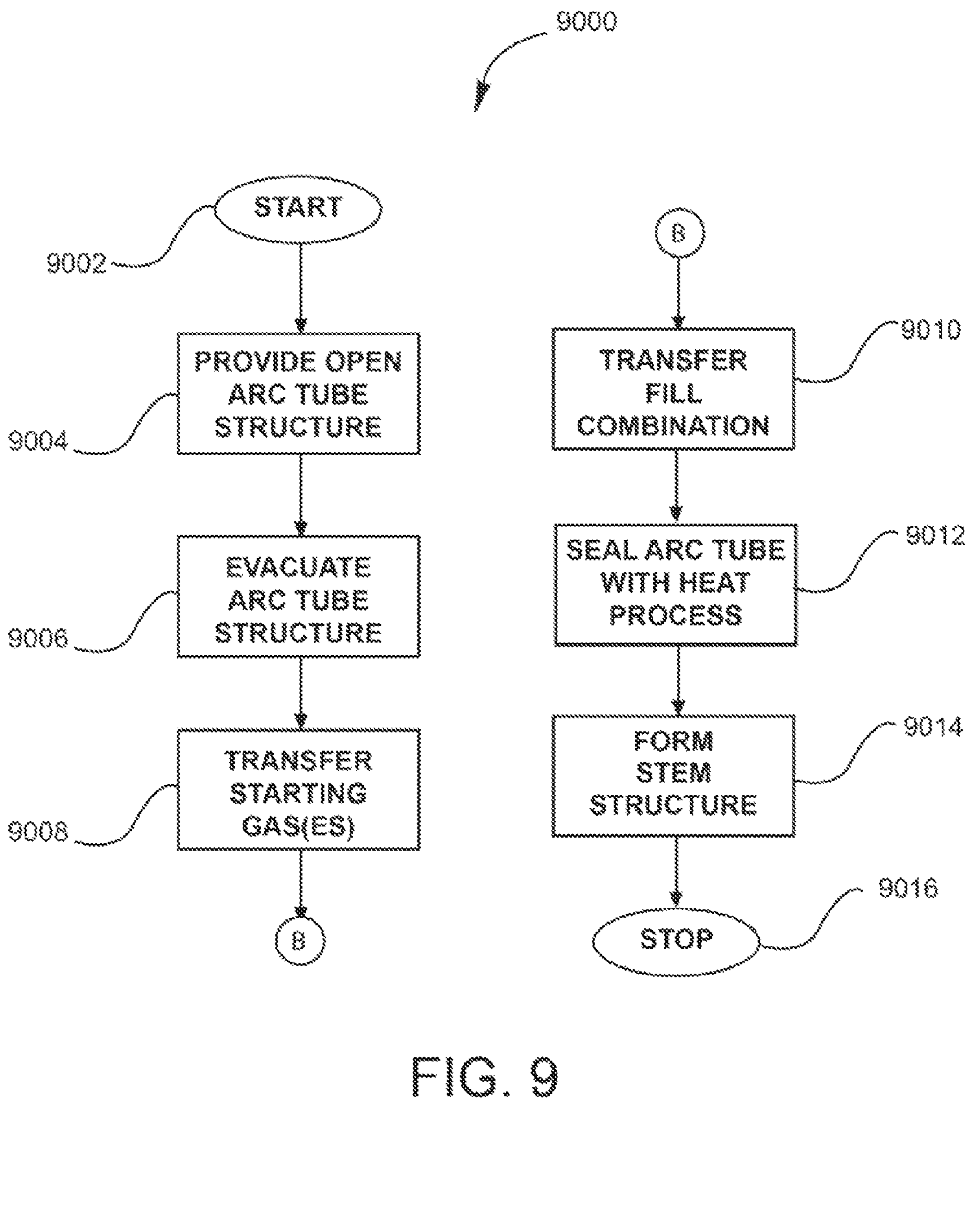

9000
START
9002
PROVIDE OPEN ARC TUBE STRUCTURE
9004
EVACUATE ARC TUBE STRUCTURE
9006
TRANSFER STARTING GAS(ES)
9008
B
B
TRANSFER FILL COMBINATION
9010
SEAL ARC TUBE WITH HEAT PROCESS
9012
FORM STEM STRUCTURE
9014
STOP
9016

FIG. 9

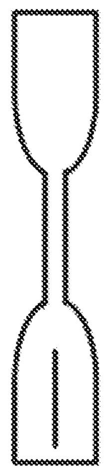


FIG. 10A

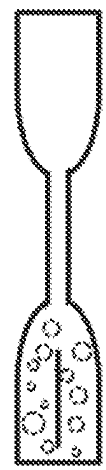


FIG. 10B

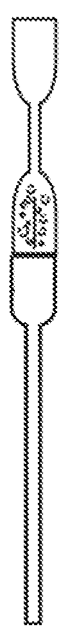


FIG. 10C

FIG. 10D

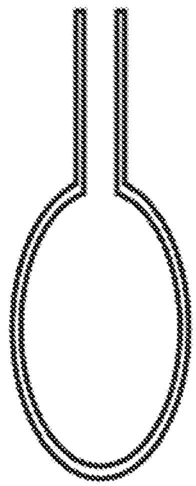


FIG. 10E

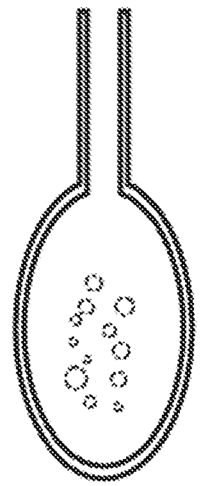


FIG. 10F

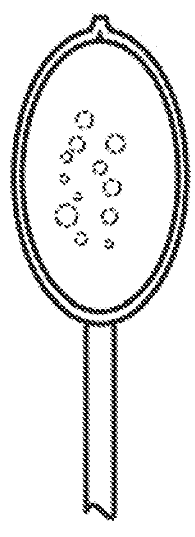


FIG. 10G

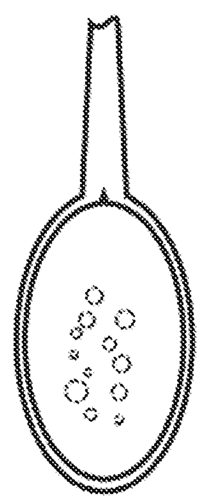


FIG. 10H

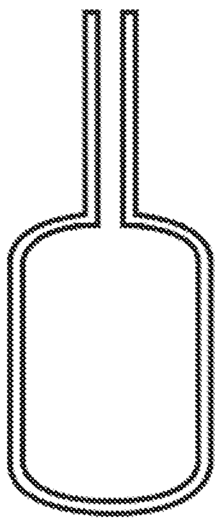


FIG. 10I

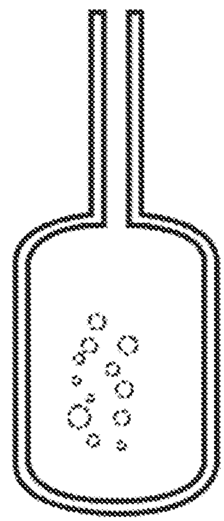


FIG. 10J

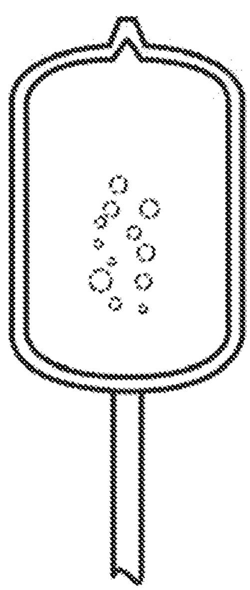
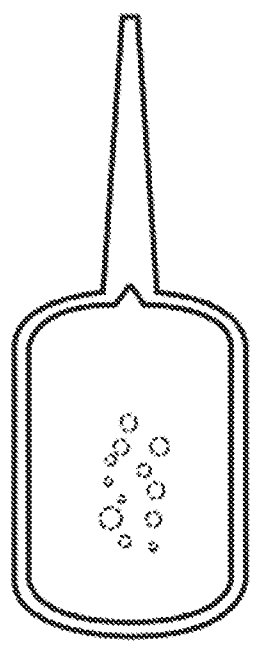


FIG. 10K



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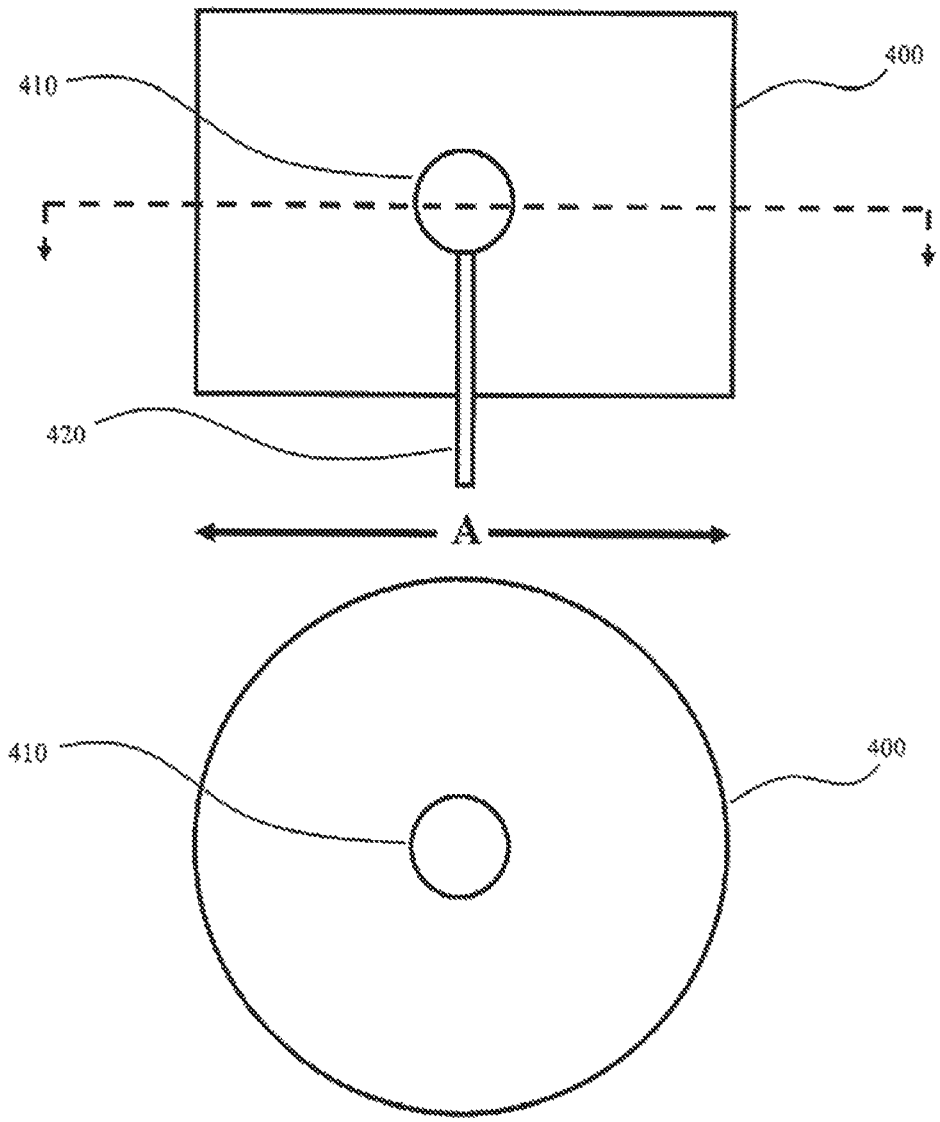

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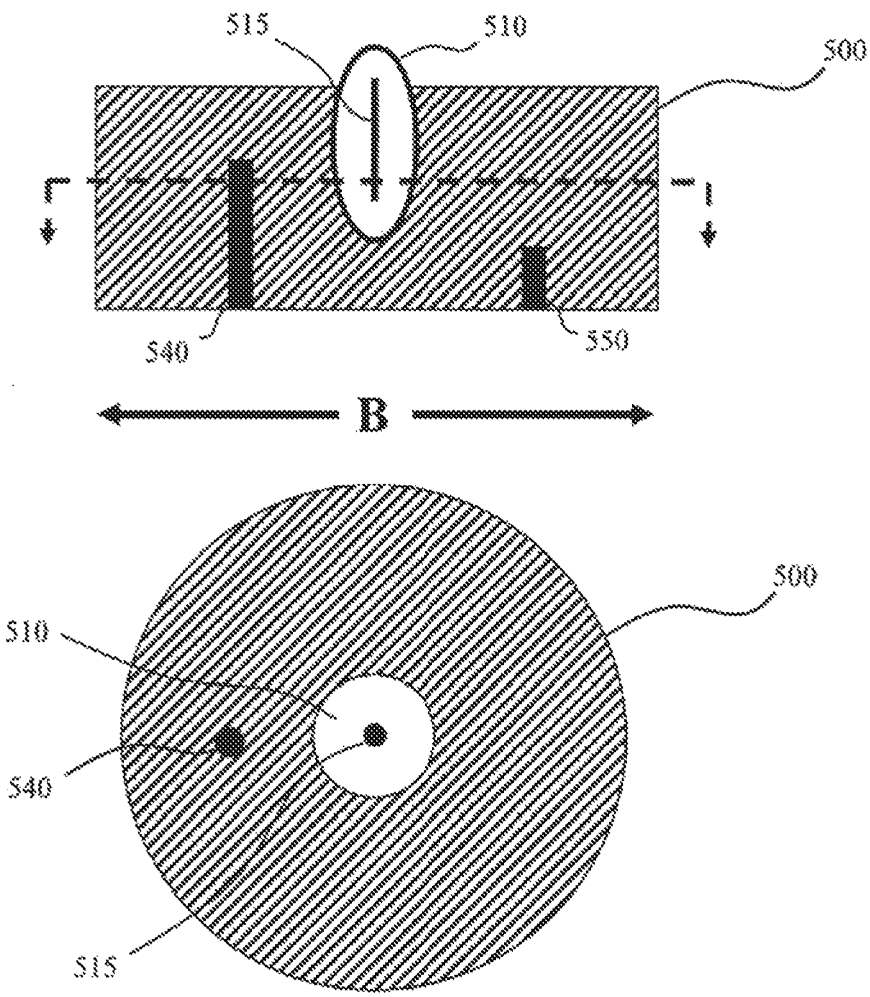

FIG. 12

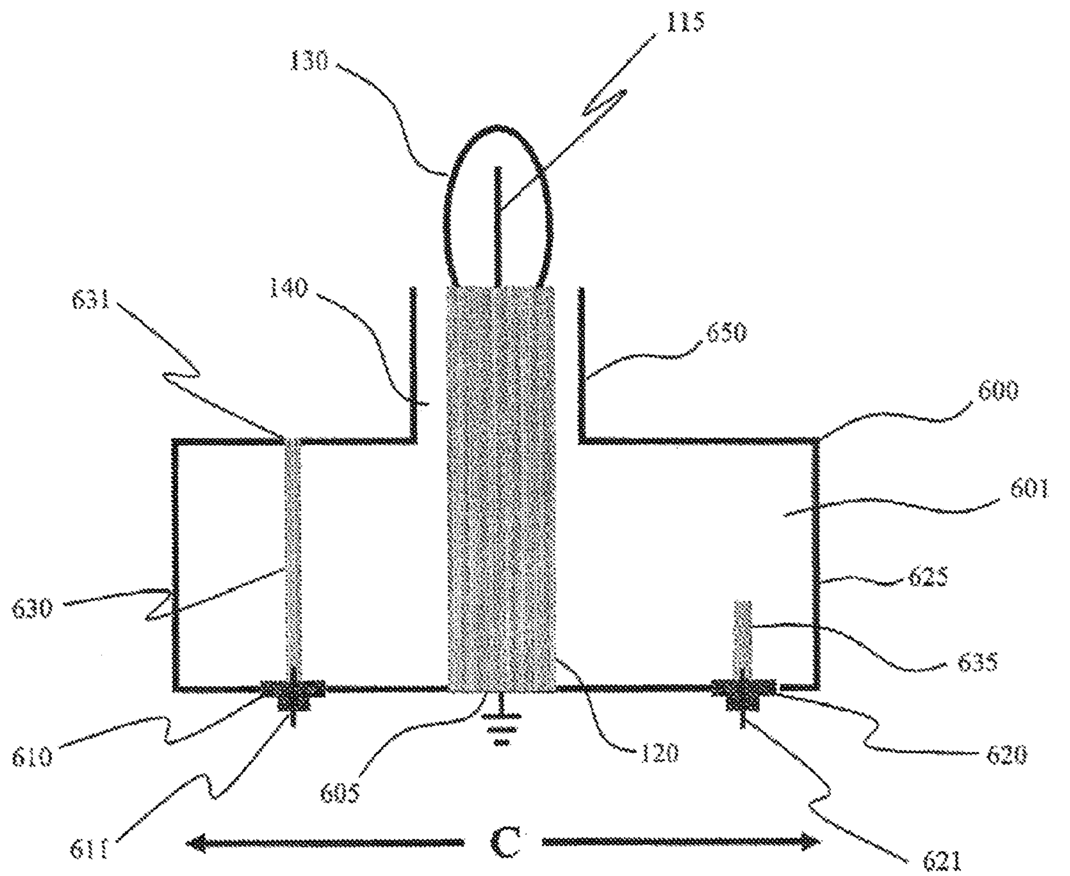

FIG. 13

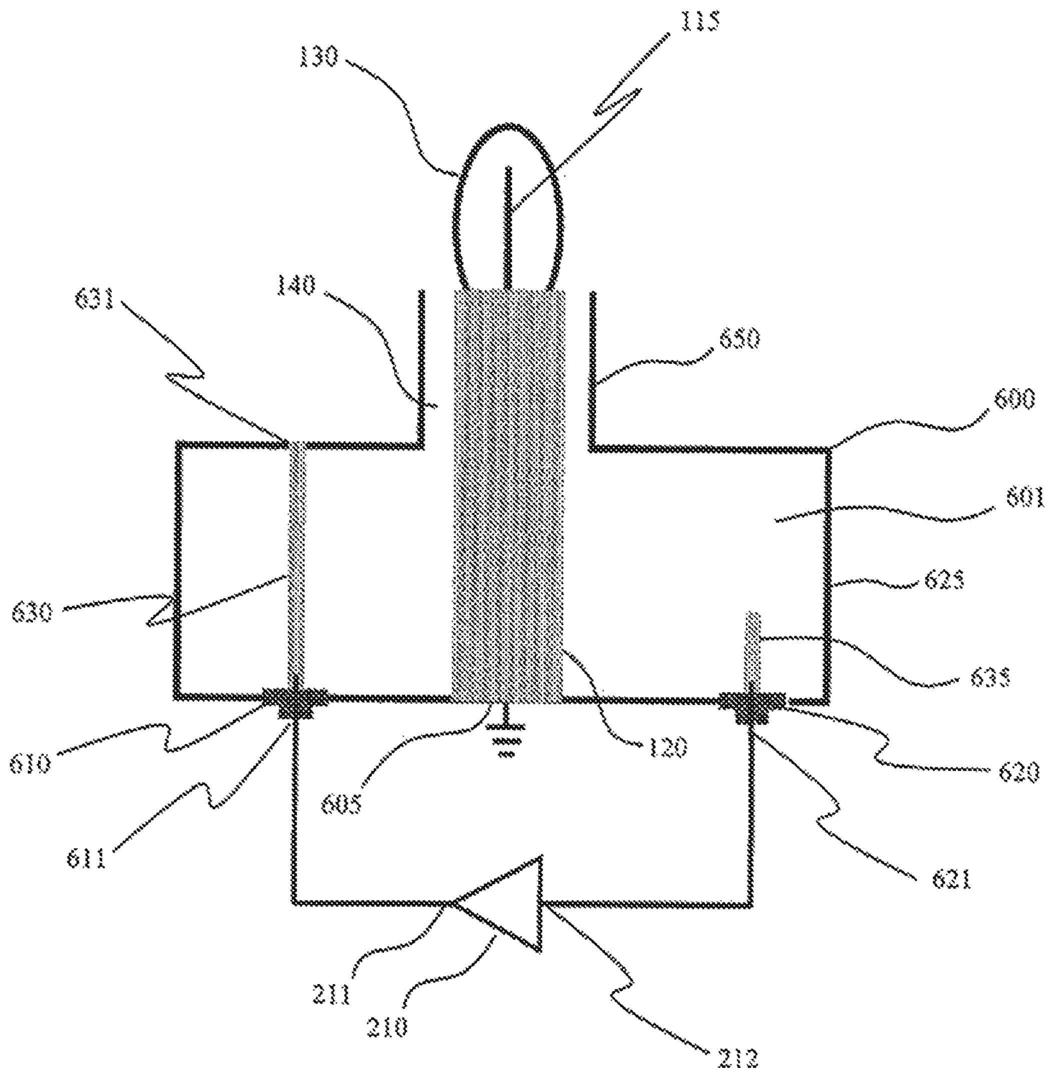
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FIG. 14

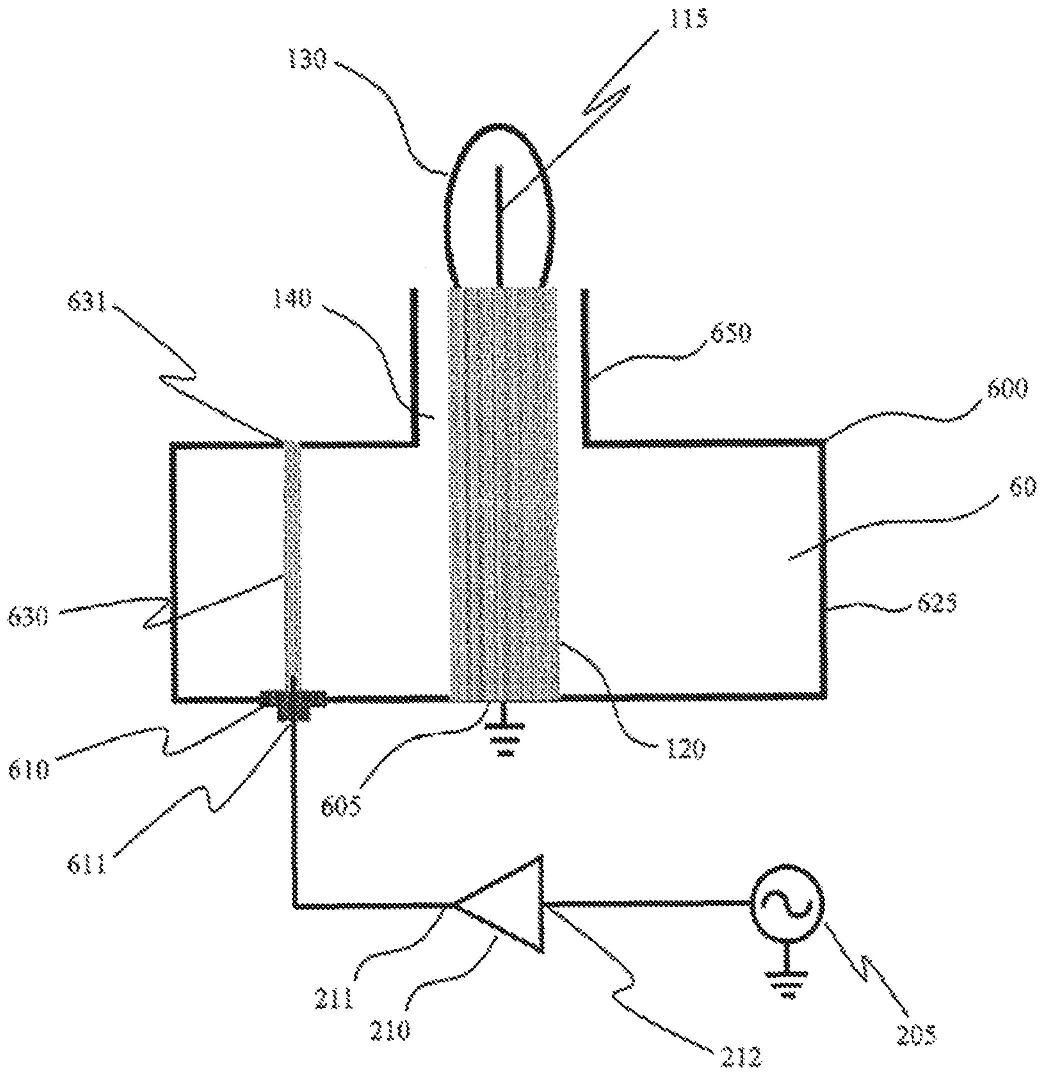
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FIG. 15A

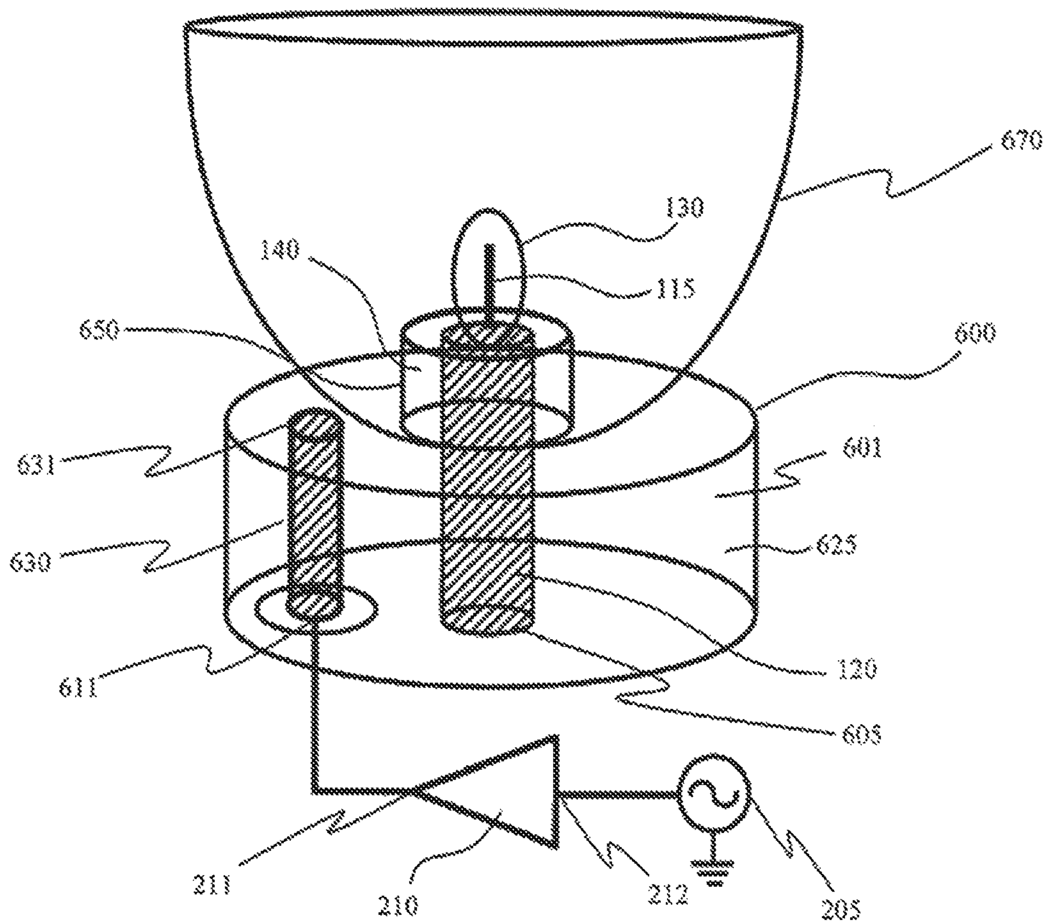
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FIG. 15B

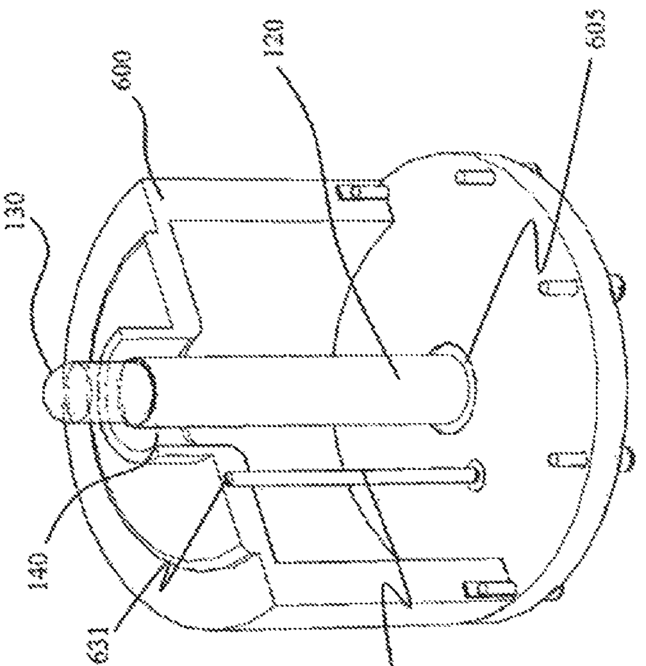

FIG. 16B

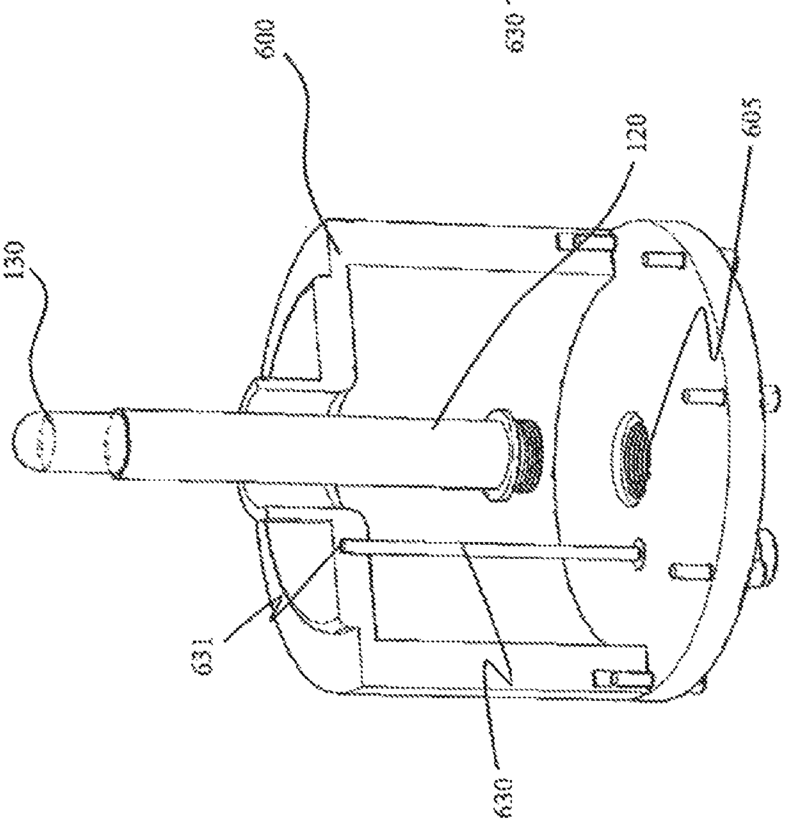

FIG. 16A

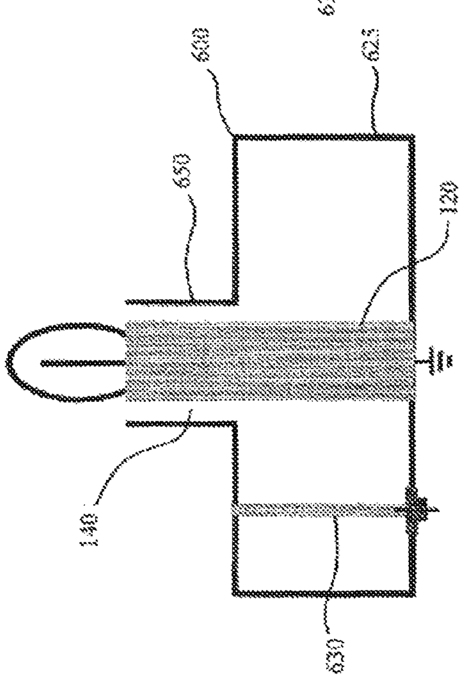

FIG. 17A

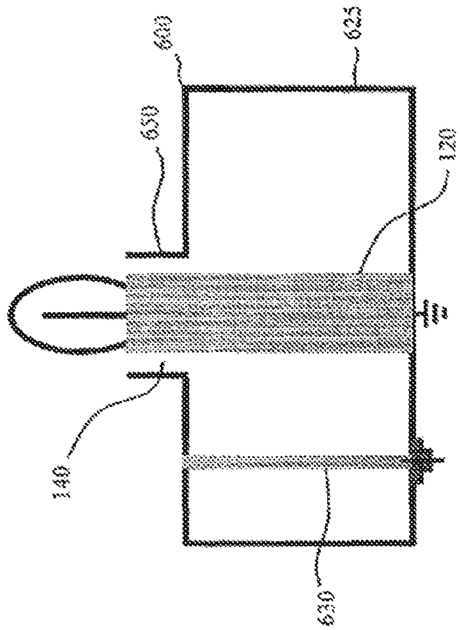

FIG. 17B

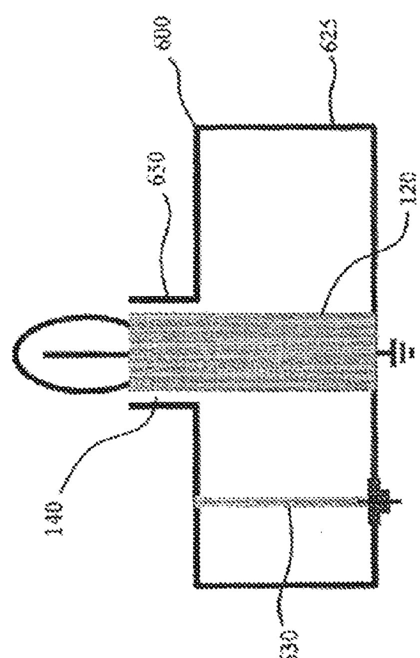

FIG. 17C

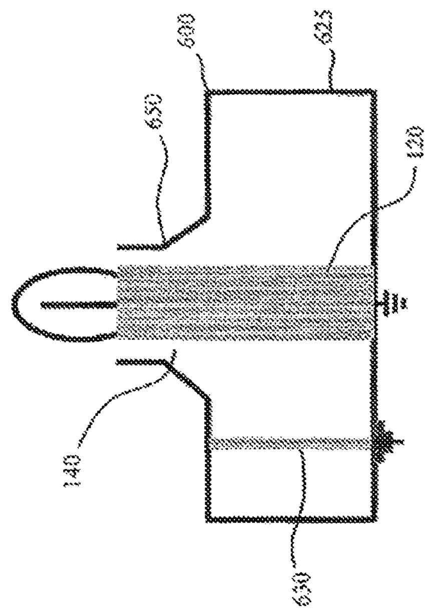

FIG. 17D

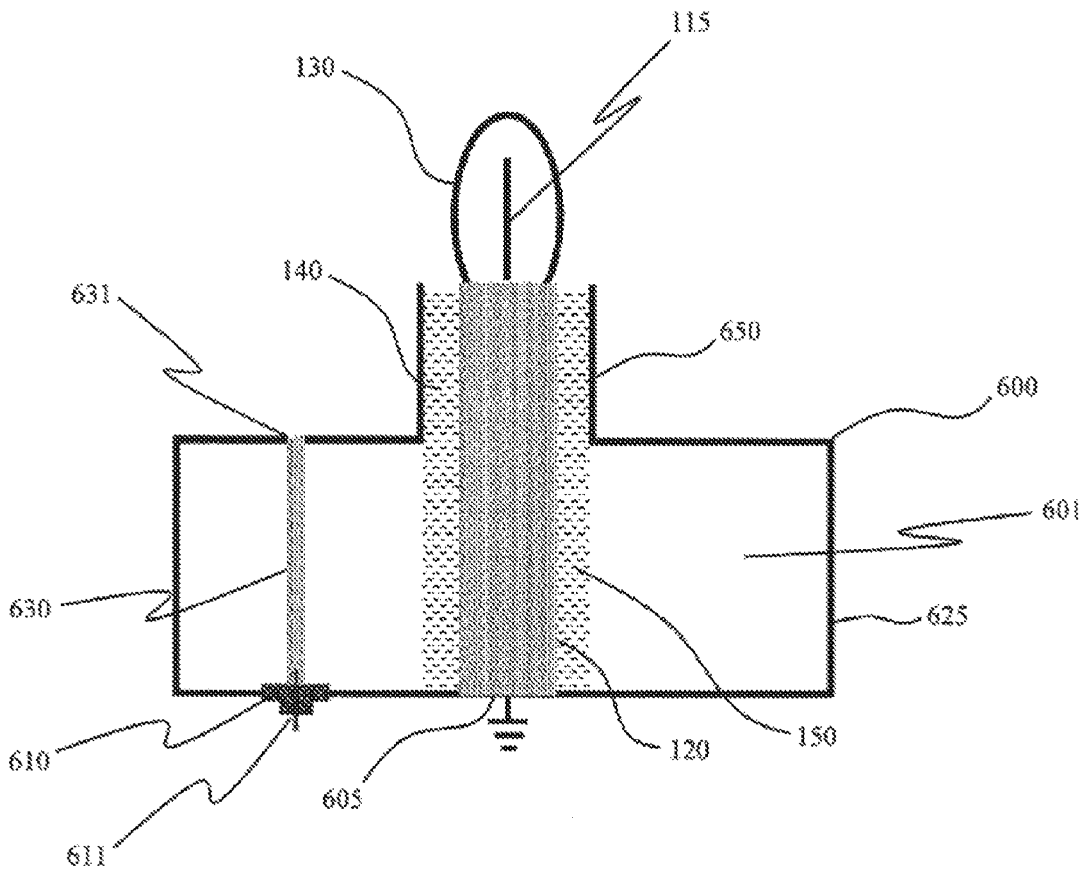

FIG. 18

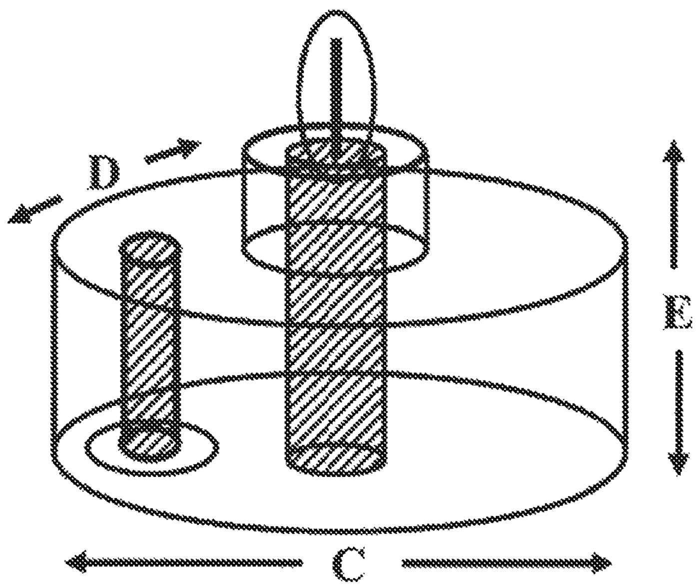

FIG. 19

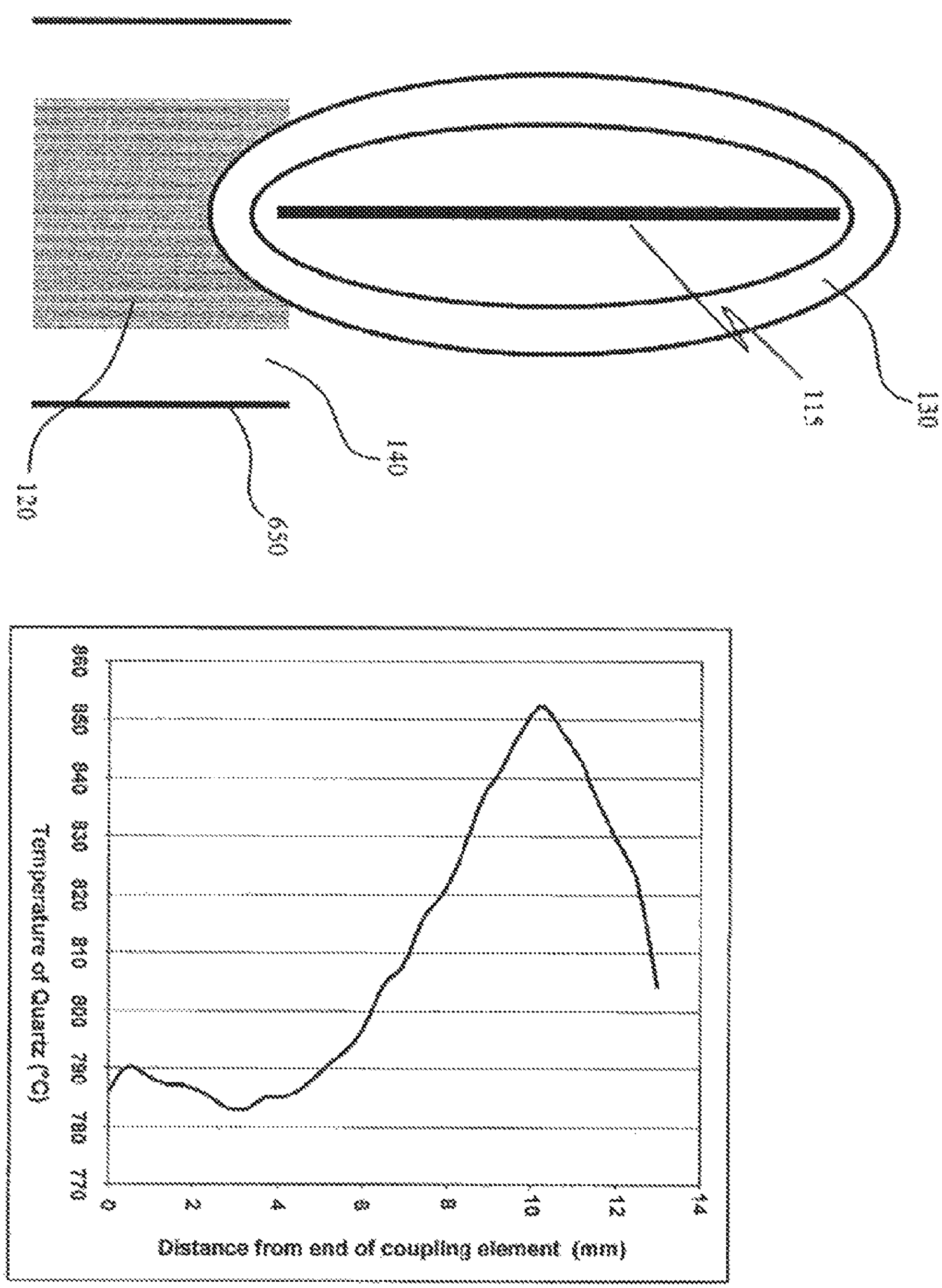
120
650
140
115
130
Temperature of Quartz (°C)
770
780
790
800
810
820
830
840
850
860
0
2
4
6
8
10
12
14
Distance from end of coupling element (mm)

FIG. 20

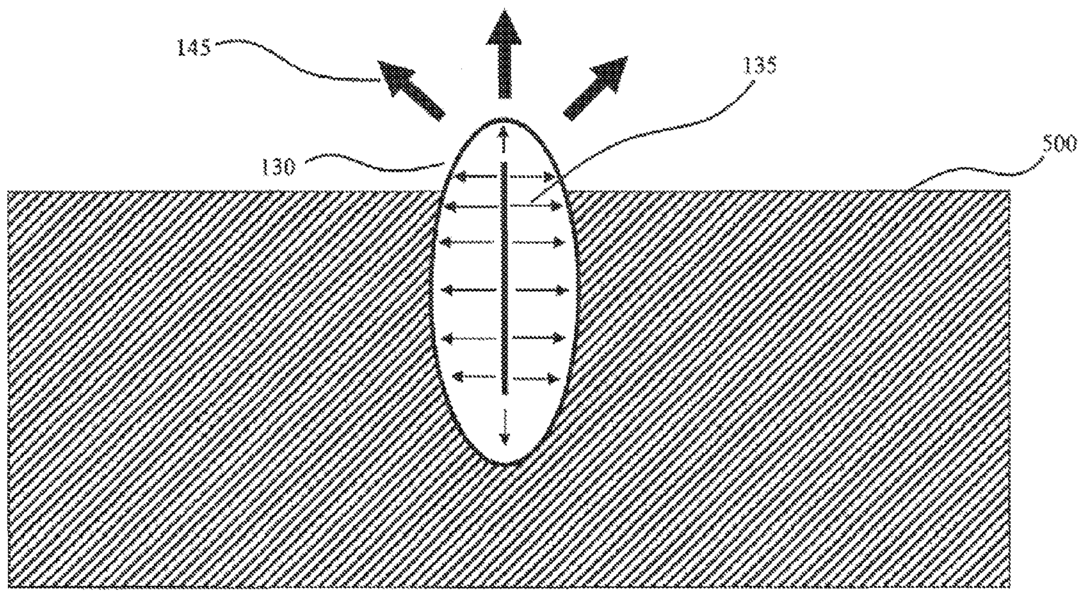

FIG. 21A

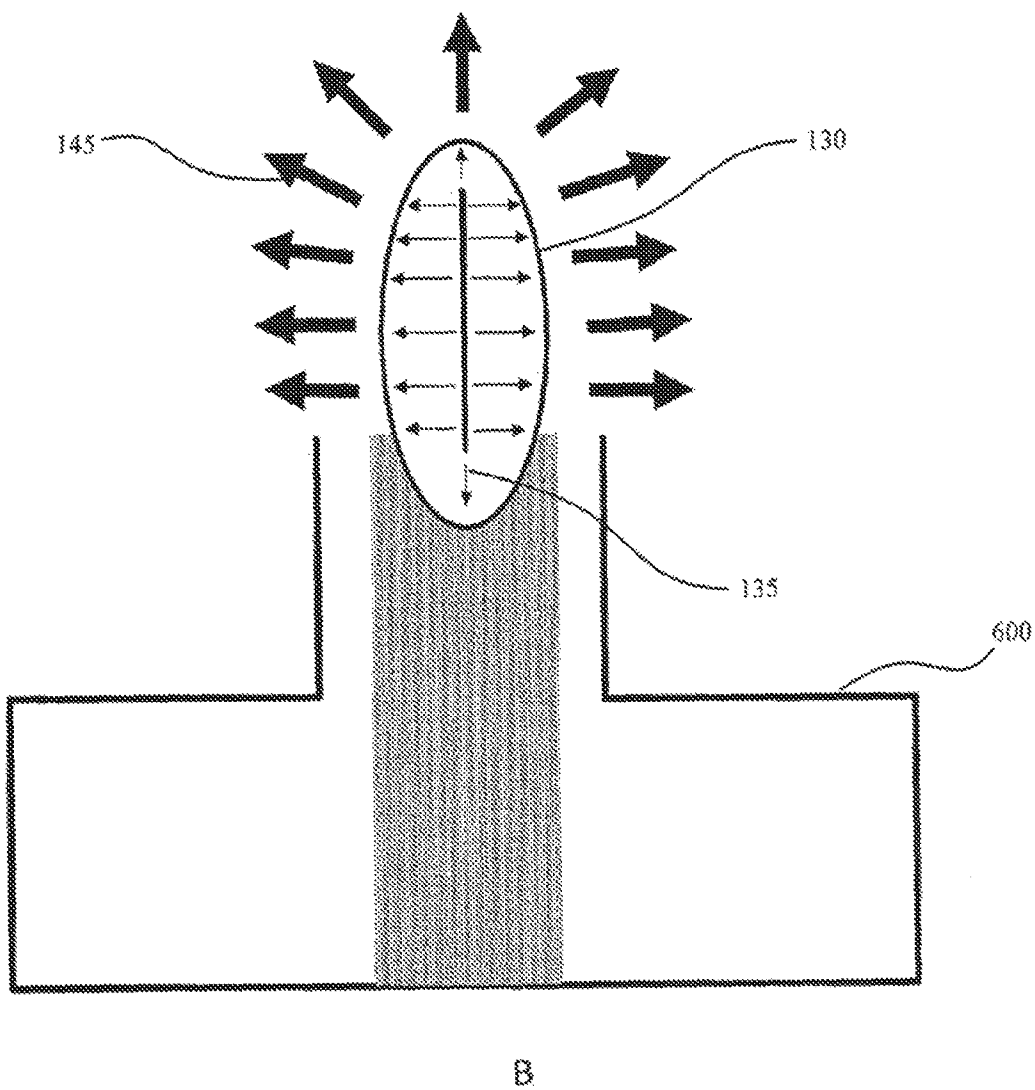

FIG. 21B

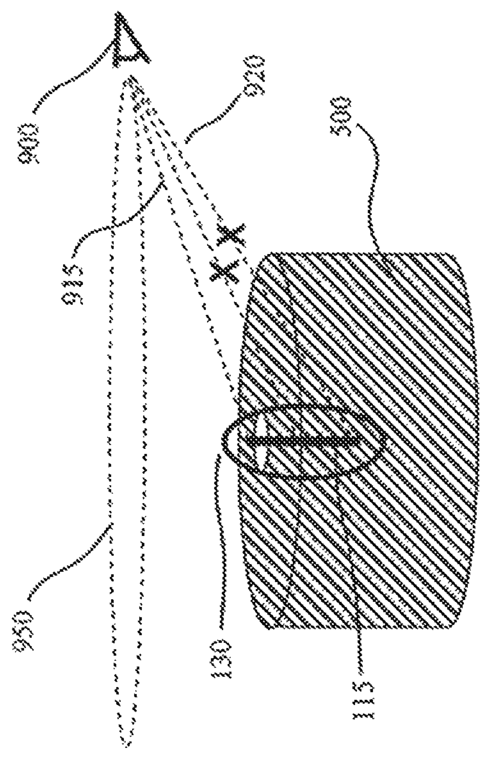

FIG. 22A

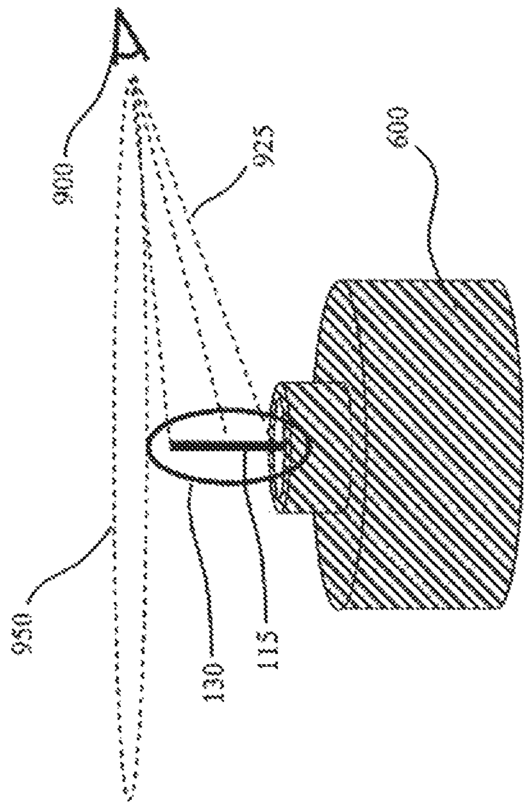

FIG. 22B

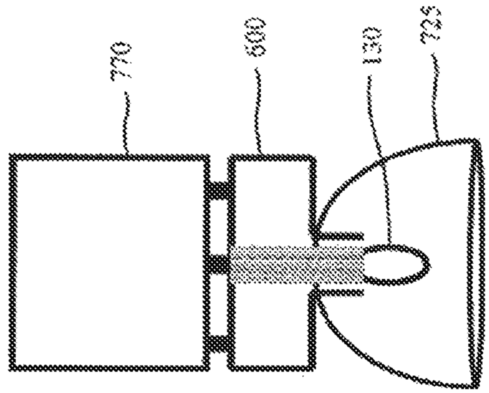

FIG. 23B

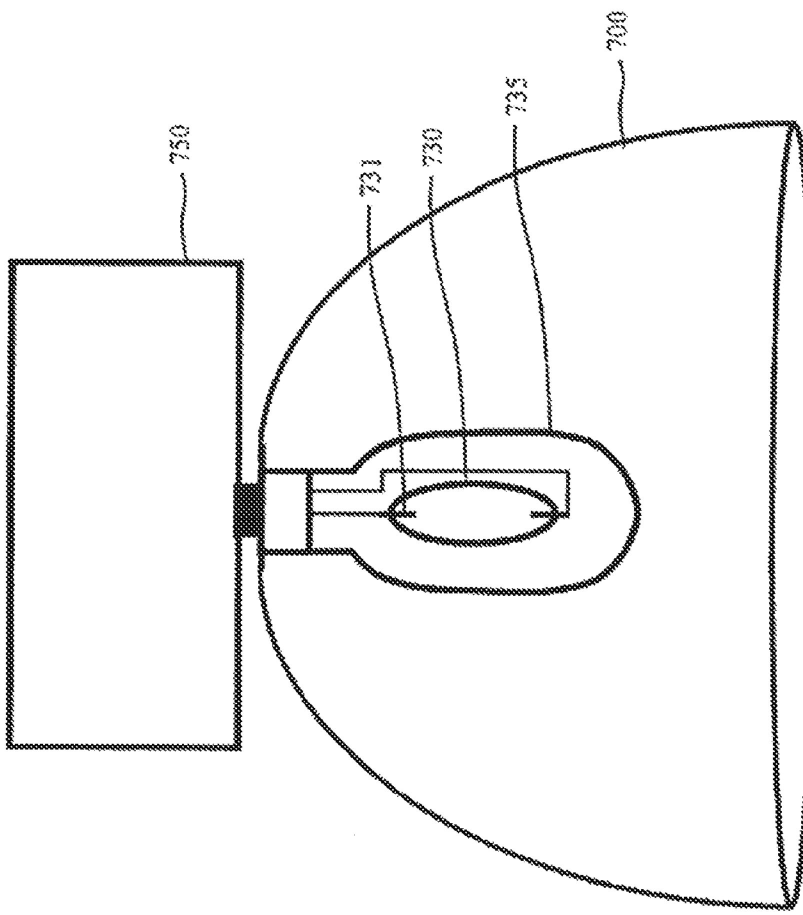

FIG. 23A

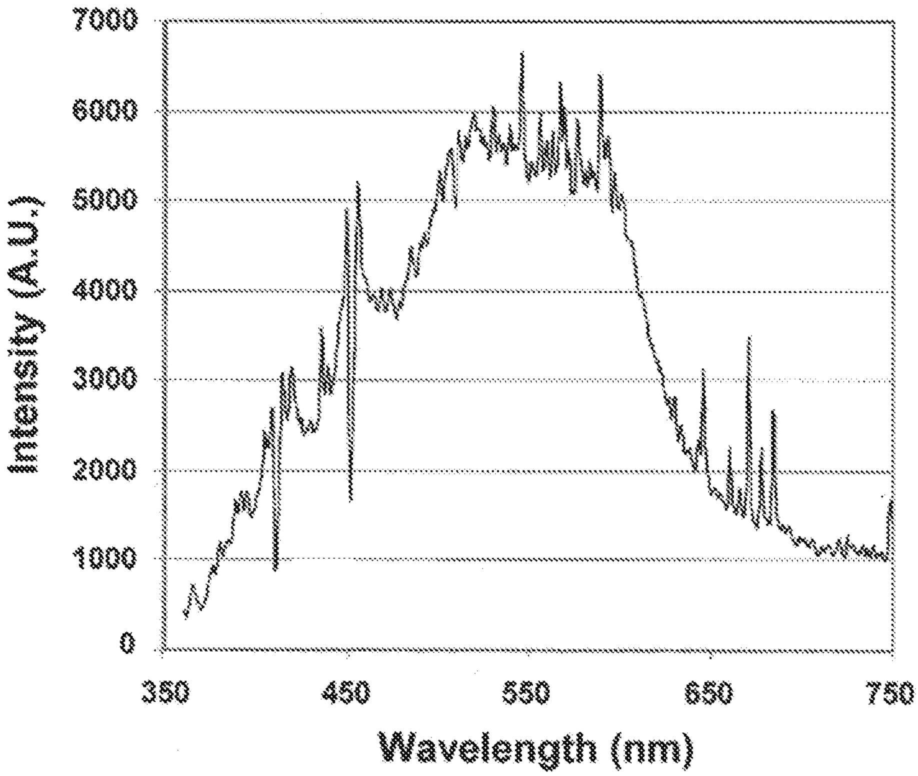
7000
6000
5000
4000
3000
2000
1000
0
Intensity (A.U.)
350
450
550
650
750
Wavelength (nm)

FIG. 24

ARC TUBE DEVICE AND STEM STRUCTURE FOR ELECTRODELESS PLASMA LAMP

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a divisional patent application of U.S. patent application Ser. No. 13/004,868, filed Jan. 11, 2011, which is incorporated by reference for all purposes. The present application incorporates by reference, for all purposes, the following pending patent application: U.S. patent application Ser. No. 12/484,933, filed Jun. 15, 2009.

BACKGROUND OF THE INVENTION

The present invention relates generally to lighting techniques. In particular, the present invention provides a method and device using a plasma lighting device having a arc tube configured for an electrode-less plasma lamp using an radio frequency source. Merely by way of example, such plasma lamps can be applied to applications such as stadiums, security, parking lots, military and defense, streets, large and small buildings, vehicle headlamps, aircraft landing, bridges, warehouses, ultraviolet (UV) water treatment, agriculture, architectural lighting, stage lighting, medical illumination, microscopes, projectors and displays, any combination of these, and the like.

From the early days, human beings have used a variety of techniques for lighting. Early humans relied on fire to light caves during hours of darkness. Fire often consumed wood for fuel. Wood fuel was soon replaced by candles, which were derived from oils and fats. Candles were then replaced, at least in part by lamps. Certain lamps were fueled by oil or other sources of energy. Gas lamps were popular and still remain important for outdoor activities such as camping. In the late 1800, Thomas Edison, who is the greatest inventor of all time, conceived the incandescent lamp, which uses a tungsten filament within a bulb, coupled to a pair of electrodes. Many conventional buildings and homes still use the incandescent lamp, commonly called the Edison bulb. Although highly successful, the Edison bulb consumed much energy and was generally inefficient.

Fluorescent lighting replaced incandescent lamps for certain applications. Fluorescent lamps generally consist of a tube containing a gaseous material, which is coupled to a pair of electrodes. The electrodes are coupled to an electronic ballast, which helps ignite the discharge from the fluorescent lighting. Conventional building structures often use fluorescent lighting, rather than the incandescent counterpart. Fluorescent lighting is much more efficient than incandescent lighting, but often has a higher initial cost.

Shuji Nakamura pioneered the efficient blue light emitting diode, which is a solid state lamp. The blue light emitting diode forms a basis for the white solid state light, which is often a blue light emitting diode within a bulb coated with a yellow phosphor material. Blue light excites the phosphor material to emit white lighting. The blue light emitting diode has revolutionized the lighting industry to replace traditional lighting for homes, buildings, and other structures.

Another form of lighting is commonly called the electrode-less lamp, which can be used to discharge light for high intensity applications. Frederick M. Espiau was one of the pioneers that developed an improved electrode-less lamp. Such electrode-less lamp relied upon a solid ceramic resonator structure, which was coupled to a fill enclosed in a bulb. The bulb was coupled to the resonator structure via rf feeds, which transferred power to the fill to cause it to discharge high intensity lighting. Although somewhat successful, the electrode-less lamp still had many limitations. As an example, electrode-less lamps have not been successfully deployed. Additionally, electrode-less lamps are generally difficult to disassemble and assembly leading to inefficient use of such lamps. These and other limitations may be described throughout the present specification and more particularly below.

From the above, it is seen that improved techniques for lighting are highly desired.

BRIEF SUMMARY OF THE INVENTION

According to the present invention, techniques for lighting are provided. In particular, the present invention provides a method and device using a plasma lighting device having a arc tube configured for an electrode-less plasma lamp using an radio frequency source. Merely by way of example, such plasma lamps can be applied to applications such as stadiums, security, parking lots, military and defense, streets, large and small buildings, vehicle headlamps, aircraft landing, bridges, warehouses, ultraviolet (UV) water treatment, agriculture, architectural lighting, stage lighting, medical illumination, microscopes, projectors and displays, any combination of these, and the like.

In a specific embodiment, the present invention provides a plasma lamp apparatus. The apparatus has an arc tube structure having an inner region and an outer region in one or more embodiments. The arc tube structure has a first end comprising an associated first end diameter and a second end comprising a second end diameter according to a specific embodiment. The apparatus also has a center region provided between the first end and the second end in one or more embodiments. The center region has a center diameter, which is less than a first end diameter and/or a second end diameter.

In one or more preferred embodiments, the smaller spatial region within a vicinity of the center region of the arc tube causes distribution of condensate to improve the illumination pattern and also redistribute the thermal profile. Of course, there can be other variations, modifications, and alternatives.

In an alternative embodiment, the present invention provides an arc tube having a stem structure protruding from at least one end of the arc tube. Preferably, the arc tube may also include any of the features noted herein.

Benefits are achieved over pre-existing techniques using the present invention. In a specific embodiment, the present invention provides a method and device having configurations of input, output, and feedback coupling elements that provide for electromagnetic coupling to the bulb whose power transfer and frequency resonance characteristics that are largely independent of the conventional dielectric resonator, but can also be dependent upon conventional designs. In a preferred embodiment, the present invention provides a method and configurations with an arrangement that provides for improved manufacturability as well as design flexibility. Other embodiments may include integrated assemblies of the output coupling element and bulb that function in a complementary manner with the present coupling element configurations and related methods for street lighting applications. Still further, the present method and device provide for improved heat transfer characteristics, as well as further simplifying manufacturing and/or retrofitting of existing and new street lighting, such as lamps, and the like. In a specific embodiment, the present method and resulting structure are relatively simple and cost effective to manufacture for commercial applications. In a specific embodiment, the present invention includes a helical resonator structure, which increases inductance and therefore reduces the resonating frequency of a device. In a preferred embodiment, the present method and device uses an novel arc tube structure having desirable characteristics. Depending upon the embodiment, one or more of these benefits may be achieved. These and other benefits may be described throughout the present specification and more particularly below.

The present invention achieves these benefits and others in the context of known process technology. However, a further understanding of the nature and advantages of the present invention may be realized by reference to the latter portions of the specification and attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present invention and its advantages will be gained from a consideration of the following description of preferred embodiments, read in conjunction with the accompanying drawings provided herein. In the figures and description, numerals indicate various features of the invention, and like numerals referring to like features throughout both the drawings and the description.

FIG. **1**A is a generalized schematic of a gas-fill vessel being driven by an RF source, and capacitively coupled to the source; to optimize lamp efficiency and light output, a plurality of impedance matching networks are present between the RF source and the resonator and between the resonator and gas-fill vessel according to an embodiment of the present invention;

FIG. **1**B is a generalized schematic of a gas-fill vessel being driven by an RF source, and inductively coupled to the source; to optimize lamp efficiency and light output, a plurality of impedance matching networks are present between the RF source and the resonator and between the resonator and gas-fill vessel according to an embodiment of the present invention;

FIG. **2**A is a simplified perspective view of an external resonator electrodeless lamp, comprising a lamp body, input and feedback coupling elements, an integrated bulb/output coupling element assembly, an external reflector, and an external RF amplifier according to an embodiment of the present invention;

FIG. **2**B is a simplified perspective view of an alternate external resonator electrodeless lamp, comprising a lamp body, input coupling element, an integrated bulb/output coupling element assembly, an external reflector, and an external RF source that may comprise an oscillator and an amplifier according to an embodiment of the present invention;

FIG. **2**C is a simplified perspective view of an alternate external resonator electrodeless lamp, comprising a lamp body, input and feedback coupling elements, an integrated bulb/output coupling element assembly, and an external RF amplifier according to an embodiment of the present invention;

FIG. **3**A is a simplified perspective view of an integrated bulb/output coupling element assembly comprising multiple sections including an output coupling element, a gas-fill vessel that is the bulb, and top coupling-element according to an embodiment of the present invention;

FIG. **3**B is a simplified side-cut view of the integrated bulb/output coupling-element assembly shown in FIG. **3**A comprising multiple sections including an output coupling-element, a gas-fill vessel that is the bulb, and a top coupling-element according to an embodiment of the present invention.

FIGS. **4**A-C are simplified diagrams of a plasma lamp apparatus according to an embodiment of the present invention;

FIGS. **5**A-C are simplified diagrams of a plasma lamp apparatus according to an embodiment of the present invention;

FIGS. **6**A-C are simplified diagrams of a plasma lamp apparatus according to an embodiment of the present invention;

FIG. **7** is a simplified diagram of an intensity field simulation for a plasma lamp apparatus according to an embodiment of the present invention;

FIG. **8** is a simplified flow diagram of a method for manufacturing a plasma lamp apparatus according to an embodiment of the present invention;

FIG. **9** is a simplified flow diagram of a method for manufacturing a plasma lamp apparatus according to an embodiment of the present invention;

FIGS. **10**A-L are simplified diagrams of a plasma lamp apparatus during various phases of manufacturing according to an embodiment of the present invention;

FIG. **11** illustrates an example of conventional air resonator/waveguide coupling RF energy to a gas filled vessel (bulb);

FIG. **12** illustrates an example of conventional dielectric resonator/waveguide coupling RF energy to a gas-fill vessel (bulb);

FIG. **13** is a simplified drawing of an embodiment of the present invention of a compact air resonator/waveguide comprising a conductive lamp body with air inside, an input coupling element, an integrated bulb/output coupling element, and a feedback coupling element;

FIG. **14** illustrates a simplified diagram of the lamp in FIG. **13** with an amplifier connected between the feedback coupling element and the input coupling element providing for frequency selective oscillation in the feedback loop according to an embodiment of the present invention;

FIG. **15**A illustrates a simplified diagram of the lamp in FIG. **13** without the feedback coupling element. An RF source that may comprise an oscillator and an amplifier is connected to the input coupling element according to an embodiment of the present invention;

FIG. **15**B is a simplified perspective view of the lamp in FIG. **15**A showing the input coupling element, the integrated bulb/output coupling element assembly consisting of the output coupling element and a gas filled vessel (bulb), and a reflector according to an embodiment of the present invention;

FIG. **16**A is a simplified cross-sectional perspective view of the lamp in FIG. **15**B without the RF source and the reflector according to an embodiment of the present invention;

FIG. **16**B shows a simplified diagram of the cross-sectional perspective view in FIG. **16**A with the integrated bulb/output coupling element screwed into the bottom of the conductive lamp body according to an embodiment of the present invention;

FIGS. **17**A, **17**B, **17**C, and **17**D illustrate simplified diagrams of some alternative variations in the design of the compact air resonator/waveguide to achieve the same resonant frequency according to embodiments of the present invention;

FIG. **18** shows a simplified diagram of another embodiment of the present invention in which a dielectric sleeve is inserted around the output coupling element;

FIG. **19** is similar to FIG. **15**B showing an embodiment of the compact air resonator/waveguide without the reflector and the RF source. The maximum dimensions of the compact air resonator/waveguide are less than one half of the free space wavelength of the resonant frequency of the fundamental mode of the air resonator/waveguide;

FIG. **20** shows a simplified diagram of the temperature profile of the surface of the gas filled vessel (in this case a quartz bulb) as a function of the distance above the output coupling element. In this case the bulb is operated in the vertical direction;

FIG. **21**A shows a simplified cross sectional view of a gas filled vessel in a conventional dielectric resonator showing that the majority of the light from the arc gets reflected back into the bulb before eventually exiting the top surface of the bulb;

FIG. **21**B shows a simplified cross sectional view of a gas filled vessel in one of the embodiments of this invention showing that the majority of the light from the arc in this case does not get reflected back into the bulb before exiting the surface of the bulb;

FIG. **22**A shows a simplified diagram of a perspective view of a conventional dielectric resonator demonstrating that from the perspective of a viewer only the top portion of the arc is visible and the view to the majority of the arc is blocked by the opaque dielectric resonator

FIG. **22**B shows a simplified diagram of a perspective view of one of the embodiments of this invention demonstrating that from the perspective of a viewer the majority of the arc is visible including as the viewer moves 360 degrees around the air resonator/waveguide;

FIG. **23**A shows a simplified diagram of a luminaire using a conventional metal halide lamp with electrodes inside the bulb;

FIG. **23**B shows a simplified diagram of a luminaire using one of the embodiments of this invention using a very compact gas filled vessel which is acting as a point light source; and

FIG. **24** shows a simplified diagram of an example of the spectrum emitted from one of the embodiments of this invention. The spectrum has emission in the visible, ultraviolet, and infrared region of the spectrum.

DETAILED DESCRIPTION OF THE INVENTION

According to the present invention, techniques for lighting are provided. In particular, the present invention provides a method and device using a plasma lighting device having a arc tube configured for an electrode-less plasma lamp using an radio frequency source. Merely by way of example, such plasma lamps can be applied to applications such as stadiums, security, parking lots, military and defense, streets, large and small buildings, vehicle headlamps, aircraft landing, bridges, warehouses, uv water treatment, agriculture, architectural lighting, stage lighting, medical illumination, microscopes, projectors and displays, any combination of these, and the like.

The following description is presented to enable one of ordinary skill in the art to make and use the invention and to incorporate it in the context of particular applications. Various modifications, as well as a variety of uses in different applications will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to a wide range of embodiments. Thus, the present invention is not intended to be limited to the embodiments presented, but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

In the following detailed description, numerous specific details are set forth in order to provide a more thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without necessarily being limited to these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention.

The reader's attention is directed to all papers and documents which are filed concurrently with this specification and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference. All the features disclosed in this specification, (including any accompanying claims, abstract, and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

Furthermore, any element in a claim that does not explicitly state "means for" performing a specified function, or "step for" performing a specific function, is not to be interpreted as a "means" or "step" clause as specified in 35 U.S.C. Section 112, Paragraph 6. In particular, the use of "step of" or "act of" in the Claims herein is not intended to invoke the provisions of 35 U.S.C. 112, Paragraph 6.

Please note, if used, the labels left, right, front, back, top, bottom, forward, reverse, clockwise and counter clockwise have been used for convenience purposes only and are not intended to imply any particular fixed direction. Instead, they are used to reflect relative locations and/or directions between various portions of an object. Additionally, the terms "first" and "second" or other like descriptors do not necessarily imply an order, but should be interpreted using ordinary meaning.

As background for the reader, we would like to describe conventional lamps and their limitations that we discovered. Electrodeless plasma lamps driven by microwave sources have been proposed. Conventional configurations include a gas filled vessel (bulb) containing Argon and a light emitter such as Sulfur or Cesium Bromide (see for example, U.S. Pat. No. 6,476,557B1 and FIG. **1** wherein). The bulb is positioned inside an air resonator/waveguide with the microwave energy provided by a source such as a magnetron and introduced into the resonator/waveguide to heat and ionize the Argon gas and vaporize the Sulfur to emit light. To use RF sources that are efficient and low-cost it is desirable to design the resonator/waveguide to operate at frequencies below approximately 2.5 GHz and preferably below 1 GHz. A conventional air resonator/waveguide operating in the fundamental resonant mode of the resonator at 1 GHz has at least one dimension that is approximately 15 cm long since this length is about half the free-space wavelength (lambda/2) of the resonant frequency of the resonator.

This results in limitations that were discovered. Such limitations include a resonator/waveguide size that is too large for most commercial lighting applications since the resonator/waveguide will not fit within typical lighting fixtures (luminaires). In addition since the bulb was placed inside the air/resonator cavity, the arc of the bulb is not accessible for use in the design of reflectors for various types of luminaires used in commercial and industrial lighting applications.

In the configuration proposed in U.S. Pat. No. 6,737,809B2, Espiau, et al., the air inside the resonator is replaced with alumina resulting in reducing the size of the resonator/waveguide since the free-space wavelength (fundamental mode guided wavelength for this resonator/waveguide) is now reduced approximately by the square-root of the effective dielectric constant of the resonator body. See also FIG. **2**. This approach has some advantages over the air resonator in U.S. Pat. No. 6,476,557B1 by reducing the size of the resonator but it has its own drawbacks. Such drawbacks may include higher manufacturing costs, losses associated with the dielectric material, and blockage of light from the bulb by the dielectric material. In this approach, the arc of the bulb is not accessible either limiting its use in various types of luminaires used in commercial and industrial lighting applications.

FIG. IA illustrates a general schematic for efficient energy transfer from RF source **1110** to gas fill vessel **1130**. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. Energy from the RF source is directed to an impedance matching network **1210** that enables the effective transfer of energy from RF source to resonating structure **1220**. An example of such impedance matching network is an E-field or H-field coupling element, but can be others. Another impedance matching network **1230**, in turn, enables efficient energy transfer from resonator to gas fill vessel **1130** according to an embodiment of the present invention. An example of the impedance matching network is an E-field or H-field coupling element. Of course, there can be other variations, modifications, and alternatives.

In a specific embodiment, the gas filled vessel is made of a suitable material such as quartz or other transparent or translucent material. The gas filled vessel is filled with an inert gas such as Argon and a fluorophor such as Mercury, Sodium, Dysprosium, Sulfur or a metal halide salt such as Indium Bromide, Scandium Bromide, or Cesium Iodide (or it can simultaneously contain multiple fluorophors). Mercury, Thalium Iodide, and Indium Bromide according to a specific embodiment. The gas filled vessel can also includes a metal halide, or other metal pieces that will discharge electromagnetic radiation according to a specific embodiment. Of course, there can be other variations, modifications, and alternatives.

In a specific embodiment, a capacitive coupling structure **1131** is used to deliver RF energy to the gas fill within the bulb **1130**. As is well known, a capacitive coupler typically comprises two electrodes of finite extent enclosing a volume and couples energy primarily using at least Electric fields (E-fields). As can be appreciated by one of ordinary skill in the art, the impedance matching networks **1210** and **1230** and the resonating structure **1220**, as depicted in schematic form here, can be interpreted as equivalent-circuit models of the distributed electromagnetic coupling between the RF source and the capacitive coupling structure. The use of impedance matching networks also allows the source to have an impedance other than 50 ohm; this may provide an advantage with respect to RF source performance in the form of reduced heating or power consumption from the RF source. Lowering power consumption and losses from the RF source would enable a greater efficiency for the lamp as a whole. As can also be appreciated by one of ordinary skill in the art, the impedance matching networks **1210** and **1230** are not necessarily identical.

FIG. **1**B illustrates a general schematic for efficient energy transfer from RF source **1110** to gas fill vessel **1130**. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. Energy from the RF source is directed to an impedance matching network **1210** that enables the effective transfer of energy from RF source to resonating structure **1220**. Another impedance matching network **1230**, in turn, enables efficient energy transfer from resonator to gas fill vessel **1130**. An inductive coupling structure **1140** is used to deliver RF energy to the gas fill within the bulb **1130**. As is well known, an inductive coupler typically comprises a wire or a coil-like wire of finite extent and couples energy primarily using magnetic fields (H-fields). As can be appreciated by one of ordinary skill in the art, the impedance matching networks **1210** and **1230** and the resonating structure **1220**, as depicted in schematic form here, can be interpreted as equivalent-circuit models of the distributed electromagnetic coupling between the RF source and the inductive coupling structure. The use of impedance matching networks also allows the source to have an impedance other than 50 ohm; this may provide an advantage with respect to RF source performance in the form of reduced heating or power consumption from the RF source. Lowering power consumption and losses from the RF source would enable a greater efficiency for the lamp as a whole. As can also be appreciated by one of ordinary skill in the art, the impedance matching networks **1210** and **1230** are not necessarily identical.

FIG. **2**A is a perspective view of an electrodeless lamp, employing a lamp body **1600**, whose outer surface **1601** is electrically conductive and is connected to ground. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. A cylindrical lamp body is depicted, but rectangular or other shapes may be used. This conductivity may be achieved through the application of a conductive veneer, or through the choice of a conductive material. An example embodiment of conductive veneer is silver paint or alternatively the lamp body can be made from sheet of electrically conductive material such as aluminum. An integrated bulb/output coupling-element assembly **1100** is closely received by the lamp body **1600** through opening **1610**. The bulb/output coupling-element assembly **1100** contains the bulb **1130**, which is a gas-fill vessel that ultimately produces the luminous output.

One aspect of the invention is that the bottom of the assembly **1100**, output coupling-element **1120**, is grounded to the body **1600** and its conductive surface **1601** at plane **1101**. The luminous output from the bulb is collected and directed by an external reflector **1670**, which is either electrically conductive or if it is made from a dielectric material has an electrically conductive backing, and which is attached to and in electrical contact with the body **1600**. Another aspect of the invention is that the top of the assembly **1100**, top coupling-element **1125**, is grounded to the body **1600** at plane **1102** via the ground strap **1710** and the reflector **1670**. Alternatively, the reflector **1670** may not exist, and the ground strap makes direct electrical contact with the body **1600**. Reflector **1670** is depicted as parabolic in shape with bulb **1130** positioned near its focus. Those of ordinary skill in the art will recognize that a wide variety of possible reflector shapes can be designed to satisfy beam-direction requirements. In a specific embodiment, the shapes can be conical, convex, concave, trapezoidal, pyramidal, or any combination of these, and the like. The shorter feedback E-field coupling-element **1635** couples a small amount of RF energy from the bulb/output coupling-element assembly **1100** and provides feedback to the RF amplifier input **1211** of RF amplifier **1210**. Feedback coupling-element **1635** is closely received by the lamp body **1600** through opening **1612**, and as such is not in direct DC electrical contact with the conductive surface **1601** of the lamp body. The input coupling-element **1630** is conductively connected with RF amplifier output **1212**. Input coupling-element **1630** is closely received by the lamp body **1600** through opening **1611**, and as such is not in direct DC electrical contact with the conductive surface **1601** of the lamp body. However, it is another key aspect of the invention that the top of the input coupling-element is grounded to the body **1600** and its conductive surface **1601** at plane **1631**.

RF power is primarily inductively coupled strongly from the input coupling-element **1630** to the bulb/output coupling-element assembly **1100** through physical proximity, their relative lengths, and the relative arrangement of their ground planes. Surface **1637** of bulb/output coupling-element assembly is covered with an electrically conductive veneer or an electrically conductive material and is connected to the body **1600** and its conductive surface **1601**. The other surfaces of the bulb/output coupling-element assembly including surfaces **1638**, **1639**, and **1640** are not covered with a conductive layer. In addition surface **1640** is optically transparent or translucent. The coupling between input coupling-element **1630** and output coupling-element **1120** and lamp assembly **1100** is found through electromagnetic simulation, and through direct measurement, to be highly frequency selective and to be primarily inductive. This frequency selectivity provides for a resonant oscillator in the circuit comprising the input coupling-element **1630**, the bulb/output coupling-element assembly **1100**, the feedback coupling-element **1635**, and the amplifier **1210**.

One of ordinary skill in the art will recognize that the resonant oscillator is the equivalent of the RF source **1110** depicted schematically in FIG. IA and FIG. 1B. A significant advantage of the invention is that the resonant frequency is strongly dependent on the relative lengths of the input and output coupling-elements, and is moreover very weakly dependent on the dimensions or dielectric properties of the lamp body **1600** itself. This permits the use of a compact lamp body whose natural resonant frequency may be much higher than the actual frequency of operation. In one example embodiment, the bottom of the lamp body **1600** may consist of a hollow aluminum cylinder with a 1.5" diameter, and a height of 0.75". The fundamental resonant frequency of such an air cavity resonator is approximately 4 GHz but by using the design described above for the input coupling-element and the output coupling-element and by adjusting the length of the output coupling-element the overall resonant frequency of the lamp assembly can be reduced to 900 MHz or no greater than about 900 MHz in a specific embodiment. Another significant advantage of the invention is that the RF power coupled to the bulb **1130** is strongly dependent on the physical separation between the input coupling-element **1630** and the output coupling-element **1120** within the bulb/output coupling-element assembly **1100**. This permits fine tuning, at assembly time, of the brightness output of a lamp which is comprised of components with relaxed dimensional tolerances. Another significant advantage of the invention is that the input coupling-element **1630** and the bulb/output coupling-element assembly **1100** are respectively grounded at planes **1631** and **1101**, which are coincident with the outer surface of the body **1600**. This eliminates the need to fine-tune their depth of insertion into the lamp body—as well as any sensitivity of the RF coupling between them to that depth—simplifying lamp manufacture, as well as improving consistency in lamp brightness yield.

FIG. **2**B is a perspective view of an electrodeless lamp that differs from that shown in FIG. **2**A only in its RF source, which is not a distributed oscillator circuit, but rather a separate oscillator **1205** conductively connected with RF amplifier input **1211** of the RF amplifier **1210**. RF amplifier output **1212** is conductively connected with input coupling-element **1630**, which delivers RF power to the lamp/output coupling-element assembly **1100**. The resonant characteristics of the coupling between the input coupling-element **1630** and the output coupling-element in the bulb/output coupling-element assembly **1100** are frequency-matched to the RF source to optimize RF power transfer. Of course, there can be other variations, modifications, and alternatives.

FIG. **2**C is a perspective view of an electrodeless lamp that is similar to the electrodeless lamp shown in FIG. **2**A except that it does not have a reflector **1670**. The top coupling-element **1125** in the bulb assembly is directly connected to the lamp body **1600** using ground straps **1715**. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives

FIG. **3**A is a perspective view of an integrated bulb/output coupling-element assembly **1100** which is the same as assembly **1100** depicted in FIGS. **2**A, **2**B, and **2**C. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. The assembly comprises a lower section **1110**, a mid-section **1111**, and upper section **1112**. Alternatively, these sections may not be physically separate. The lower section **1110** is bored to closely receive output coupling-element **1120**, which is a solid conductor. Coupling-element **1120** protrudes from the lower section **1110** at plane **1121**. It is a key aspect of this invention that coupling-element **1120** makes ground contact at plane **1121** with the lamp body **1600** depicted in FIGS. **2**A, **2**B, and **2**C. The mid-section **1111** is hollowed to closely receive the bulb **1130**, which is the gas-fill vessel that ultimately produces the lamp's luminous output. The gas-fill vessel contains an inert gas such as Argon and a fluorophor such as Mercury, Sodium, Sulfur or a metal halide salt such as Indium Bromide or Cesium Iodide (or it can simultaneously contain multiple fluorophors). Alternatively, the mid-section **1111** is hollowed, with the resulting cavity forming the volume of the bulb **1130**, making the two an integrated unit. The mid-section **1111** can be attached to the lower section **1110** and upper section **1112** using high temperature adhesive. The upper section **1112** is bored to closely receive top electrode **1125**, which is a solid conductor. Top electrode **1125** protrudes from upper section **1112** at plane **1126**. It is a key aspect of this invention that the top coupling-element **1125** makes ground contact at plane **1126** with the lamp body **1600**, as depicted in FIGS. **2**A, **2**B, and **2**C. This is through the ground strap **1710** and the reflector body **1670** or ground strap **1715**. Overall, RF energy is coupled capacitively, or inductively, or a combination of inductively and capacitively, by the output coupling-element **1120** and top coupling-element **1125** to the bulb **1130** which is made from quartz, translucent alumina, or other similar material, ionizing the inert gas and vaporizing the fluorophor resulting in intense light **1115** emitted from the lamp.

Sections **1110**, **1111**, and **1112** can all be made from the same material or from different materials. Section **1111** has to be transparent to visible light and have a high melting point such as quartz or translucent alumina. Sections **1110** and **1112** can be made from transparent (quartz or translucent alumina) or opaque materials (alumina) but they have to have low loss at RF frequencies. In the case that the same material is used for all three sections the assembly can be made from a single piece of material such as a hollow tube of quartz or translucent alumina. The upper section **1112** may be coated with a conductive veneer **1116** whose purpose is to shield electromagnetic radiation from the top-electrode **1125**. The lower section **1110** may be partially coated with a conductive veneer **1117** whose purpose is to shield electromagnetic radiation from the output coupling-element **1120**. The partial coating would extend to the portion of the lower section **1110** that protrudes from the lamp body **1600**, as depicted in FIGS.

2A, 2B, and 2C and does not overlap with input coupling-element **1630**. The plane dividing that portion that protrudes from the lamp body from that portion that does not being depicted schematically by dashed line **1140**. An example embodiment of conductive veneers **1116** and **1117** is silver paint. The outer surface of the mid section **1111** is not coated.

FIG. 3B is a side-cut view of an integrated bulb/output coupling-element assembly **1100** shown in FIG. 3A. This diagram is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. The assembly can be made from a single piece of material such as a hollow quartz tube or translucent alumina, or it can be made from three different pieces and assembled together.

FIGS. 4A-C are simplified diagrams of a plasma lamp apparatus according to an embodiment of the present invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. As shown in FIG. 4A, device **4000** can include an arc tube structure having an inner region and an outer region. In an embodiment, the arc tube structure can include a first end **4010** associated with a first end diameter and a second end **4020** associated with a second end diameter. Device **4000** can also have a center region **4030** that is provided between first end **4010** and second end **4020**. Center region **4030** can have a center diameter that is less than the first or second end diameter. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

In a specific embodiment, the arc tube structure can be configured with an aspect ratio ranging from about three halves to about three. Structures configured with aspect ratios outside of this range can be prone to performance instabilities, such as moving plasma, fluctuating lumen values, or undesired cold regions and the like. Also, the arc tube structure can be made of a quartz, translucent alumina, or other material or combination thereof. Second end **4020** can be elevated relative to first end **4010**, or vice versa. An arc **4040** can be substantially exposed from center region **4030** to second end **4020**. In a specific embodiment, center region **4030** can be spatially configured to cause a uniform temperature profile within the inner region from the center region to the second region. Center region **4030** can also be configured to maintain a vicinity of the inner region within a proximity of center region **4030** substantially free from an opaque fluid material. The arc tube structure can also be coupled to an rf source or an rf coupling element that is coupled to an rf source. Also, the arc tube structure can be coupled to a resonator, or other related device or combination of devices thereof. Those skilled in the art will recognize other variations, modifications, and alternatives.

As shown in FIG. 4B, device **4100** can include an arc tube structure having an inner region and an outer region. In an embodiment, the arc tube structure can include a first end **4110** associated with a first end diameter and a second end **4120** associated with a second end diameter. Device **4100** can also have a center region **4130** that is provided between first end **4110** and second end **4120**. Center region **4130** can have a center diameter that is less than the first or second end diameter. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

In a specific embodiment, the arc tube structure can be configured with an aspect ratio ranging from about three halves to about three. Structures configured with aspect ratios outside of this range can be prone to performance instabilities, such as moving plasma, fluctuating lumen values, or undesired cold regions and the like. Also, the arc tube structure can be made of a quartz, translucent alumina, or other material or combination thereof. Second end **4120** can be elevated relative to first end **4110**, or vice versa. An arc can be substantially exposed from center region **4130** to second end **4120**. In a specific embodiment, center region **4130** can be spatially configured to cause a uniform temperature profile within the inner region from the center region to the second region. Center region **4130** can also be configured to maintain a vicinity of the inner region within a proximity of center region **4130** substantially free from an opaque fluid material. The are tube structure can also be coupled to an rf source or an rf coupling element that is coupled to an rf source. Also, the arc tube structure can be coupled to a resonator, or other related device or combination of devices thereof. Those skilled in the art will recognize other variations, modifications, and alternatives.

As shown in FIG. 4C, device **4200** can include an arc tube structure having an inner region and an outer region. In an embodiment, the arc tube structure can include a first end **4210** associated with a first end diameter and a second end **4220** associated with a second end diameter. Device **4200** can also have a center region **4230** that is provided between first end **4210** and second end **4220**. Center region **4230** can have a center diameter that is less than the first or second end diameter. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

In a specific embodiment, the arc tube structure can be configured with an aspect ratio ranging from about three halves to about three. Structures configured with aspect ratios outside of this range can be prone to performance instabilities, such as moving plasma, fluctuating lumen values, or undesired cold regions and the like. Also, the arc tube structure can be made of a quartz, translucent alumina, or other material or combination thereof. Second end **4220** can be elevated relative to first end **4210**, or vice versa. An arc can be substantially exposed from center region **4230** to second-end **4220**. In a specific embodiment, center region **4230** can be spatially configured to cause a uniform temperature profile within the inner region from the center region to the second region. Center region **4230** can also be configured to maintain a vicinity of the inner region within a proximity of center region **4230** substantially free from an opaque fluid material. The arc tube structure can also be coupled to an rf source or an rf coupling element that is coupled to an rf source. Also, the arc tube structure can be coupled to a resonator, or other related device or combination of devices thereof. Those skilled in the art will recognize other variations, modifications, and alternatives.

In a specific embodiment, Device **4000**, **4100**, or **4200** can also include a fill material, which can be disposed within the inner region of the arc tube structure. The fill material can be configured to discharge a substantially white light. The discharged light can be representative of a black body source and can provide at least 120 lumens per watt. The fill material can include thulium bromide, indium bromide, dysprosium bromide, and Argon. In a specific embodiment, the amount of thulium bromide can range from about one third to about four thirds mg/cm^3. The amount of indium bromide can range also range from about one third to about four thirds mg/cm^3. The same range of dysprosium bromide can be used in the fill material as well. On the other hand, the amount of mercury can range from about 10 to about 13.333 mg/cm^3. The mercury can be liquid mercury, which can be selectively metered. In other embodiments, the amounts of elements in the fill material can vary and the ratios between elements can differ. The amount of dysprosium bromide can be a determined amount to cause a selected color temperature, which can range from about 4000 Kelvin to about 5000 Kelvin. Also, the amount of Argon can be about 200 Torr. Of course, there can be other variations, modifications, and alternatives.

FIGS. **5**A-C are simplified diagrams of a plasma lamp apparatus according to an embodiment of the present invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. As shown in FIG. **5**A, device **5000** can include an arc tube structure having an inner region and an outer region and a stem structure **4050**. In an embodiment, the arc tube structure can include a first end **4010** associated with a first end diameter and a second end **4020** associated with a second end diameter. Device **5000** can also have a center region **4030** that is provided between first end **4010** and second end **4020**. Center region **4030** can have a center diameter that is less than the first or second end diameter. A detailed description of the components found within the arc tube structure can be found above in the description for FIGS. **4**A-C. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

In a specific embodiment, stem structure **4050** can be a solid structure or a hollow structure. Stem structure **4050** can be shaped in a rod like manner or be configured to be inserted into a support member. In other embodiments, stem structure **4050** can be integrated from at least one end of the arc tube structure, which can be a quartz rod structure that is integrally coupled to the arc tube structure. Of course, those skilled in the art will recognize other variations, modifications, or alternatives.

As shown in FIG. **5**B, device **5100** can include an arc tube structure having an inner region and an outer region and a stem structure **4150**. In an embodiment, the arc tube structure can include a first sealed end **4111** associated with a first end diameter and a second end **4120** associated with a second end diameter. Device **5100** can also have a center region that is provided between first sealed end **4111** and second end **4120**. The center region can have a center diameter that is less than the first or second end diameter. A detailed description of the components found within the arc tube structure can be found above in the description for FIGS. **4**A-C. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

In a specific embodiment, stem structure **4150** can be a solid structure or a hollow structure. Stem structure **4150** can be shaped in a rod like manner or be configured to be inserted into a support member. In other embodiments, stem structure **4150** can be integrated from at least one end of the arc tube structure, which can be a quartz rod structure that is integrally coupled to the are tube structure. Of course, those skilled in the art will recognize other variations, modifications, or alternatives.

As shown in FIG. **5**C, device **5200** can include an arc tube structure having an inner region and an outer region and a stem structure **4250**. In an embodiment, the arc tube structure can include a first sealed end **4211** associated with a first end diameter and a second end **4220** associated with a second end diameter. Device **5200** can also have a center region that is provided between first sealed end **4211** and second end **4220**. The center region can have a center diameter that is less than the first or second end diameter. A detailed description of the components found within the are tube structure can be found above in the description for FIGS. **4**A-C. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

In a specific embodiment, stem structure **4250** can be a solid structure or a hollow structure. Stem structure **4250** can be shaped in a rod like manner or be configured to be inserted into a support member. In other embodiments, stem structure **4250** can be integrated from at least one end of the arc tube structure, which can be a quartz rod structure that is integrally coupled to the arc tube structure. Of course, those skilled in the art will recognize other variations, modifications, or alternatives.

FIGS. **6**A-C are simplified diagrams of a plasma lamp apparatus according to an embodiment of the present invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. As shown in FIG. **6**A, device **6000** can include an arc tube structure having an inner region and an outer region, a stem structure **4050**, and a support member **4060**. In an embodiment, the arc tube structure can include a first end **4010** associated with a first end diameter and a second end **4020** associated with a second end diameter. Device **6000** can also have a center region **4030** that is provided between first end **4010** and second end **4020**. Center region **4030** can have a center diameter that is less than the first or second end diameter. A detailed description of the components found within the are tube structure and stem structure can be found above in the descriptions for FIGS. **4**A-C and FIGS. **5**A-C. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

As shown in FIG. **6**B, device **6100** can include an arc tube structure having an inner region and an outer region, a stem structure **4150**, and a support member **4160**. In an embodiment, the arc tube structure can include a first sealed end **4111** associated with a first end diameter and a second end **4120** associated with a second end diameter. Device **6100** can also have a center region that is provided between first sealed end **4111** and second end **4120**. The center region can have a center diameter that is less than the first or second end diameter. A detailed description of the components found within the arc tube structure and stem structure can be found above in the descriptions for FIGS. **4**A-C and FIGS. **5**A-C. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

As shown in FIG. **6**C, device **6200** can include an arc tube structure having an inner region and an outer region, a stem structure **4250**, and a support member **4260**. In an embodiment, the arc tube structure can include a first sealed end **4211** associated with a first end diameter and a second end **4220** associated with a second end diameter. Device **6200** can also have a center region that is provided between first sealed end **4211** and second end **4220**. The center region can have a center diameter that is less than the first or second end diameter. A detailed description of the components found within the arc tube structure and stem structure can be found above in the descriptions for FIGS. **4**A-C and FIGS. **5**A-C. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

FIG. **7** is a simplified diagram of an intensity field simulation for a plasma lamp apparatus according to an embodiment of the present invention. This diagram is merely an example, which should not unduly limit the scope of the claims herein. This figure shows the simulation results of microwave electric field intensity inside the arc tube structure at one moment in time during operation. An arc tube structure **7010** and a resonator **7020** are shown. The intensity of the field is indicated by the length of the arrows, which shows the highest intensity near one end of the arc tube structure. It can be noted that the field intensity is independent of the orientation of the lighting device in which the arc tube is installed.

FIG. **8** is a simplified flow diagram of a method for manufacturing a plasma lamp apparatus according to an embodiment of the present invention. It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this process and scope of the appended claims.

As shown in FIG. **8**, the present method can be briefly outlined below.

1. Start;
2. Provide an arc tube structure;
3. Evacuate the arc tube structure;
4. Transfer starting gas(es) to the arc tube structure;
5. Transfer fill material to the arc tube structure;
6. Subject the are tube structure to a heat process;
7. Couple the stem structure to the arc tube structure; and
8. Stop.

These steps are merely examples and should not unduly limit the scope of the claims herein. As shown, the above method provides a way of manufacturing a plasma lamp apparatus according to an embodiment of the present invention. One of ordinary skill in the art would recognize many other variations, modifications, and alternatives. For example, various steps outlined above may be added, removed, modified, rearranged, repeated, and/or overlapped, as contemplated within the scope of the invention.

As shown in FIG. **8**, method **8000** begins at start, step **8002**. The present method provides a manufacturing method for a plasma lamp apparatus. Many benefits are achieved by way of the present invention over conventional techniques. These and other benefits will be described in more throughout the present specification.

Following step **8002**, an arc tube structure can be provided, step **8004**. In a specific embodiment, the are tube structure can be configured with an ratio ranging from about three halves to about three. Structures configured with aspect ratios outside of this range can be prone to performance instabilities, such as moving plasma, fluctuating lumen values, or undesired cold regions and the like. The arc tube structure can have a first end associated with a first diameter, and a second end associated with a second diameter. The arc tube structure can also have a center region that is provided between first end and second end. The center region can have a center diameter that is less than the first or second end diameter. Also, the arc tube structure can be made of a quartz, translucent alumina, or other material or combination thereof. The second end can be elevated relative to the first end, or vice versa. An arc can be substantially exposed from the center region to the second end. In a specific embodiment, the center region can be spatially configured to cause a uniform temperature profile within the inner region from the center region to the second region. The center region can also be configured to maintain a vicinity of the inner region within a proximity of the center region substantially free from an opaque fluid material. The arc tube structure can also be coupled to an rf source or an rf coupling element that is coupled to an rf source. Also, the arc tube structure can be coupled to a resonator, or other related device or combination of devices thereof. Those skilled in the art will recognize other variations, modifications, and alternatives.

The inner region of the arc tube structure can then be evacuated, step **8006**. The evacuation process can be done via a vacuum, motor device, or other any other evacuation device. One or more starting gases can be disposed within the inner region of the arc tube structure, step **8008**. In an embodiment, the starting gas(es) can include Argon. The amount of Argon disposed within the inner region can be about 200 Torr, or any other determined amount. A fill material can also be disposed within the inner region of the arc tube structure, step **8010**. The fill material can be configured to discharge a substantially white light. The discharged light can be representative of a black body source and can provide at least 120 lumens per watt. The fill material can include thulium bromide, indium bromide, dysprosium bromide, and Argon. In a specific embodiment, the amount of thulium bromide can range from about one third to about four thirds mg/cm^3. The amount of indium bromide can range also range from about one third to about four thirds mg/cm^3. The same range of dysprosium bromide can be used in the fill material as well. On the other hand, the amount of mercury can range from about 10 to about 13.333 mg/cm^3. The mercury can be a liquid mercury, which can be selectively metered. In other embodiments, the amounts of elements in the fill material can vary and the ratios between elements can differ. The amount of dysprosium bromide can be a determined amount to cause a selected color temperature, which can range from about 4000 Kelvin to about 5000 Kelvin. Of course, there can be other variations, modifications, and alternatives.

In another embodiment, the following substances can be provided: a first volume of a rare gas, a first mount of a first metal halide, a second amount of a second metal halide, and a third amount of mercury. The first metal halide can include indium, aluminum, gallium, or the like. The second metal halide can include at least one lanthanide element, which can include thulium, dysprosium, holmium, cerium, ytterbium, or the like. The rare gas can include argon gas, xenon gas, krypton gas, or the like. These provided substances can be combined into the fill material. Of course, there can be other variations, modifications, or alternatives.

Once the fill material has been transferred to the arc tube structure, the arc tube structure can be subjected to a heat process, step **8012**. The heat (thermal) process can be characterized by a flame at a temperature ranging from about 1500 to 2500 degrees Celsius. The heat process can also be provided by any other means of transferring energy to the arc tube structure to cause a temperature increase. Following the heat process, a stem structure can be coupled to the arc tube structure, step **8014**. The stem structure can be shaped in a rod like manner or be configured to be inserted into a support member. Of course, those skilled in the art will recognize other variations, modifications, or alternatives.

The above sequence of processes provides a manufacturing method for a plasma lamp apparatus according to an embodiment of the present invention. As shown, the method uses a combination of steps including providing an arc tube structure, evacuating the are tube structure, transferring starting gas(es) and fill material(s) into the arc tube structure, sealing the arc tube structure, and coupling the arc tube structure to a stem structure. Other alternatives can also be provided where steps are added, one or more steps are removed, or one or more steps are provided in a different sequence without departing from the scope of the claims herein.

FIG. **9** is a simplified flow diagram of a method for manufacturing a plasma lamp apparatus according to an embodiment of the present invention. It is also understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this process and scope of the appended claims.

As shown in FIG. **9**, the present method can be briefly outlined below.

1. Start;
2. Provide an open arc tube-structure;
3. Evacuate the arc tube structure;
4. Transfer starting gas(es) to the arc tube structure;
5. Transfer fill material to the are tube structure;

6. Seal the open arc tube structure via a heat process;

7. Form a stem structure at an end of the arc tube structure; and

8. Stop.

These steps are merely examples and should not unduly limit the scope of the claims herein. As shown, the above method provides a way of manufacturing a plasma lamp apparatus according to an embodiment of the present invention. One of ordinary skill in the art would recognize many other variations, modifications, and alternatives. For example, various steps outlined above may be added, removed, modified, rearranged, repeated, and/or overlapped, as contemplated within the scope of the invention.

As shown in FIG. **9**, method **9000** begins at start, step **9002**. The present method provides a manufacturing method for a plasma lamp apparatus. Many benefits are achieved by way of the present invention over conventional techniques. These and other benefits will be described in more throughout the present specification.

Following step **9002**, an open arc tube structure having an arc tube region and an open region can be provided, step **9004**. In a specific embodiment, the arc tube structure can be configured with an aspect ratio of about three halves to about three. Structures configured with aspect ratios outside of this range can be prone to performance instabilities, such as moving plasma, fluctuating lumen values, or undesired cold regions and the like. The arc tube structure can have a first end associated with a first diameter, and a second end associated with a second diameter. The arc tube structure can also have a center region that is provided between first end and second end. The center region can have a center diameter that is less than the first or second end diameter. Also, the arc tube structure can be made of a quartz, translucent alumina, or other material or combination thereof. The second end can be elevated relative to the first end, or vice versa. An arc can be substantially exposed from the center region to the second end. In a specific embodiment, the center region can be spatially configured to cause a uniform temperature profile within the inner region from the center region to the second region. The center region can also be configured to maintain a vicinity of the inner region within a proximity of the center region substantially free from an opaque fluid material. The arc tube structure can also be coupled to an rf source or an rf coupling element that is coupled to an rf source. Also, the arc tube structure can be coupled to a resonator, or other related device or combination of devices thereof. Those skilled in the art will recognize other variations, modifications, and alternatives.

The inner region of the arc tube structure can then be evacuated, step **9006**. The evacuation process can be done via a vacuum, motor device, or other any other evacuation device. One or more starting gases can be disposed within the inner region of the arc tube structure, step **9008**. In an embodiment, the starting gas(es) can include Argon. The amount of Argon disposed within the inner region can be about 200 Torr, or any other determined amount. One or more materials can also be disposed within the inner region of the arc tube structure, step **9010**. The materials can include a fill material, which can be configured to discharge a substantially white light. The discharged light can be representative of a black body source and can provide at least 120 lumens per watt. The fill material can include thulium bromide, indium bromide, dysprosium bromide, and Argon. In a specific embodiment, the amount of thulium bromide can range from about one third to about four thirds mg/cm^3. The amount of indium bromide can range also range from about one third to about four thirds mg/cm^3. The same range of dysprosium bromide can be used in the fill material as well. On the other hand, the amount of mercury can range from about 10 to about 13.333 mg/cm^3. In other embodiments, the amounts of elements in the fill material can vary and the ratios between elements can differ. The amount of dysprosium bromide can be a determined amount to cause a selected color temperature, which can range from about 4000 Kelvin to about 5000 Kelvin. Of course, there can be other variations, modifications, and alternatives.

In another embodiment, the following substances can be provided: a first volume of a rare gas, a first mount of a first metal halide, a second amount of a second metal halide, and a third amount of mercury. The first metal halide can include indium, aluminum, gallium, or the like. The second metal halide can include at least one lanthanide element, which can include thulium, dysprosium, holmium, cerium, ytterbium, or the like. The rare gas can include argon gas, xenon gas, krypton gas, or the like. These provided substances can be combined into the fill material. Of course, there can be other variations, modifications, or alternatives.

Once the fill material has been transferred to the arc tube structure, the open region of the arc tube structure can be sealed by being subjected to a heat process, step **9012**. The heat (thermal) process can be characterized by a flame at a temperature ranging from about 1500 to 2500 degrees Celsius. The heat process can also be provided by any other means of transferring energy to the arc tube structure to cause a temperature increase. Also, the heat process can be used to form a pinched region where the open region was sealed. Following the heat process, a stem structure can be formed at an end of the arc tube structure, step **9014**. The stem structure can be shaped in a rod like manner or be configured to be inserted into a support member. In a specific embodiment, the stem structure can be formed from a region within a vicinity of the pinched region. Of course, those skilled in the art will recognize other variations, modifications, or alternatives.

The above sequence of processes provides a manufacturing method for a plasma lamp apparatus according to an embodiment of the present invention. As shown, the method uses a combination of steps including providing an arc tube structure, evacuating the arc tube structure, transferring starting gas(es) and fill material(s) into the arc tube structure, sealing the arc tube structure while forming a pinched region, and forming a stem structure within a vicinity of the pinched region. Other alternatives can also be provided where steps are added, one or more steps are removed, or one or more steps are provided in a different sequence without departing from the scope of the claims herein.

FIGS. **10**A-L are simplified diagrams of a plasma lamp apparatus during various phases of manufacturing according to an embodiment of the present invention. These diagrams are merely examples, which should not unduly limit the scope of the claims herein. A detailed description of the arc tube structure, stem structure, and fill material contents can be found above in the description for FIGS. **4**A-C and FIGS. **5**A-C. As shown, the following FIGS. **10**A-L depict different stages of the manufacturing process of one or more embodiments of the present invention. Details regarding the methods of manufacturing can be found above in the descriptions for FIGS. **8** and **9**. As shown, FIGS. **10**A-D depict one embodiment of an arc tube structure, FIGS. **10**E-H depict another embodiment of the arc tube, and FIGS. I-L depict yet another embodiment of the arc tube.

FIG. **10**A shows an are tube structure, which can have an opening. FIG. **10**B shows a fill material being disposed within the inner region of the are tube structure. FIG. **10**C shows an embodiment of the stem structure wherein the stem structure is coupled to a portion of the arc tube structure. FIG. **10**D shows another embodiment of the stem structure wherein the stem structure is formed via a thermal process. There can be other variations, alternatives, and modifications.

FIG. **10**E shows another arc tube structure, which can have an opening. FIG. **10**F shows a fill material being disposed within the inner region of the arc tube structure. FIG. **10**G shows an embodiment of the stem structure wherein the stem structure is coupled to a portion of the arc tube structure. FIG. **10**H shows another embodiment of the stem structure wherein the stem structure is formed via a thermal process. As state previously, there can be other variations, alternatives, and modifications.

FIG. **10**I shows yet another arc tube structure, which can have an opening. FIG. **10**J shows a fill material being disposed within the inner region of the arc tube structure. FIG. **10**K shows an embodiment of the stem structure wherein the stem structure is coupled to a portion of the arc tube structure. FIG. **10**L shows another embodiment of the stem structure wherein the stem structure is formed via a thermal process. Of course, there can be other variations, alternatives, and modifications.

FIG. **11** illustrates an example of a conventional air resonator/waveguide coupling RF energy to a gas filled vessel (bulb). The air resonator **400** surrounds the gas filled vessel **410** that is attached to a stem **420**. The cross section of the resonator is illustrated at the bottom of FIG. **11**. The dimension A shown in the figure corresponds to the diameter of an air resonator operating at the fundamental resonant mode of 900 MHz and is approximately 16.5 cm which is about half of the free space wavelength at 900 MHz (it is typically half the free space guide wavelength which is the effective wavelength inside the waveguide). The size of this resonator is too large for most luminaires. Furthermore, the arc of the bulb is fully surrounded by the walls of the resonator making it difficult to use with conventional reflectors and optics in designing the luminaire.

FIG. **12** illustrates an example of a conventional dielectric resonator/waveguide coupling RF energy to a gas filled vessel (bulb). The RF energy is coupled into the dielectric resonator **500** using an input probe **540**. The resonator couples the RF energy to the gas filled vessel **510** that is placed inside the dielectric resonator with most of the arc **515** being surrounded by the dielectric resonator. A feedback probe **550** can be used to couple a small amount of RF energy out of the resonator and in conjunction with an amplifier and the input probe form a feedback loop to power up the lamp. The cross section of this resonator is illustrated at the bottom of FIG. **12** with dimension B corresponding to the diameter of this resonator. One advantage of this approach over an air resonator shown in FIG. **11** is that the size of the resonator (designed for fundamental mode of operation) is reduced approximately by the square root of the effective dielectric constant of the dielectric material. So for example in the case that the resonator is made from Alumina with a dielectric constant of 9.4 the diameter of a 900 MHz air resonator shown in FIG. **11** is reduced by a factor of approximately 3 to about 5.3 cm (dimension B). The drawback of this approach is that the resonator has to be made from a low RF loss dielectric material and the resonator is more expensive and more difficult to manufacture. Furthermore, most of the arc of the bulb **515** is inside the dielectric material so it is not accessible for more flexibility in the design of the optical components used in luminaires. These and other limitations have been overcome with one or more embodiments of the present invention, which will be described in more detail below.

FIG. **13** is a simplified drawing of an embodiment of the present invention of a compact air resonator/waveguide. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications. The lamp housing **600** is made from an electrically conductive material. This conductivity may be achieved through the application of a conductive veneer, or through the choice of a conductive material. An example embodiment of conductive veneer is silver paint or alternatively the lamp body can be made from sheet of electrically conductive material such as aluminum. In this embodiment the lamp body consists of a wider diameter bottom section **625** and a narrower diameter **650** top section. A cylindrical lamp body is depicted, but rectangular or other shapes may be used. The input coupling element **630** is connected to the lamp body at the top surface **631** and at the other end is connected to an RF connector **611** through the opening **610** in the lamp body. The input coupling element **630** can be made from a solid or hollow conductor or alternatively from a dielectric material with an electrically conductive coating. The output coupling element **120** is connected to the lamp body at the bottom **605** and at the other end is connected to the gas filled vessel (bulb) **130**. The output coupling element can be made from solid or hollow electrically conductive material or alternatively can be made from a dielectric material with an electrically conductive coating. The top end of the output coupling element is shaped to closely receive the gas filled vessel. In the case that the output coupling element is made from a solid conductor a thin layer of a dielectric material or refractory metal is used as an interface barrier between the bulb and the output coupling element. In a specific embodiment, the gas filled vessel is made of a suitable material such as quartz or translucent alumina or other transparent or translucent material. The gas filled vessel is filled with an inert gas such as Argon or Xenon and a light emitter such as Mercury, Sodium, Dysprosium, Sulfur or a metal halide salt such as Indium Bromide, Scandium Bromide, Thallium Iodide, Holmium Bromide, Cesium Iodide or other similar materials (or it can simultaneously contain multiple light emitters). Overall, RF energy is coupled capacitively, or inductively, or a combination of inductively and capacitively, by the output coupling-element **120** to the bulb **130**, ionizing the inert gas and vaporizing the light emitter(s) resulting in intense light emitted from the lamp. The arc of the bulb **115** in this embodiment is not surrounded by the walls of the resonator/waveguide. The feedback coupling element **635** is connected to an RF connector **621** through an opening **620** in the lamp body. The other end of the feedback coupling element is not connected to the lamp body.

The resonant frequency of the compact air resonator/waveguide depends on a number of parameters including the diameter and length of the top (**650**) and bottom (**625**) sections, the length and diameter of the output coupling element (**120**), and the gap **140** between the output coupling element and the walls of the lamp body. By adjusting these parameters as well as other parameters of the compact air resonator/waveguide it is possible to design the resonator to operate at different resonant frequencies. By adjusting the lengths and the gap between the input coupling element (**630**) and the output coupling element (**120**) it is possible to optimize coupling of the RF power between an RF source and the bulb.

In one example embodiment, the bottom **625** of the lamp body **600** may consist of a hollow aluminum cylinder with a 5 cm diameter, and a height of 3.8 cm and the top portion **650** have a diameter of 1.6 cm and a height of 1.4 cm. The diameter of the input coupling element **630** is about 0.13 cm and the diameter of the output coupling element **120** is about 0.92 cm. The fundamental resonant frequency of such an air resonator/waveguide is approximately 900 MHz. By adjusting the various design parameters (dimensions of the lamp body, length and diameter of the output coupling element, gap between the output coupling element and the walls of the lamp body) as well as other parameters it is possible to achieve different resonant frequencies. Also it is possible by adjusting various design parameters to have numerous other design possibilities for a 900 MHz resonator. Based on the above example design one can see that the diameter of this air resonator/waveguide C (5 cm) is significantly smaller than air resonator A (16.5 cm) in prior art shown in FIG. **11**. The compact air resonator/waveguide disclosed has significant advantages over conventional large air resonators and dielectric resonators. The smaller resonator size and exposed arc allows easy integration into existing luminaires. It does not require the use of expensive dielectric materials that will result in RF losses and difficulty in manufacturing. Another significant advantage of the invention is that the input coupling element **630** and the output coupling element **120** are respectively grounded at planes **631** and **605**, which are coincident with the outer surface of the lamp body **600**. This eliminates the need to fine-tune their depth of insertion into the lamp body—as well as any sensitivity of the RF coupling between them to that depth—simplifying lamp manufacture, as well as improving consistency in lamp brightness yield. This illustration is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

FIG. **14** illustrates the lamp shown in FIG. **13** with an RF amplifier **210** connected between the feedback coupling element **635** and the input coupling element **630**. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications. The shorter feedback coupling element **635** couples a small amount of RF energy from the resonator and provides feedback to the RF amplifier input **212** through an RF connector **621**. The feedback coupling element **635** is closely received by the lamp body **600** through opening **620** and as such is not in direct DC electrical contact with the conductive surface of the lamp body. The input coupling element **630** is conductively connected with RF amplifier output **211** through RF connector **611**. Input coupling element **630** is closely received by the lamp body **600** through the opening **610** and as such is not in direct electrical contact with the lamp body at the bottom surface. However, the other end of the input coupling element is connected to the lamp body **600** at **631**. The feedback loop between the feedback coupling element, the RF amplifier, the input coupling element, and the air resonator/waveguide results in oscillation as long as the amplifier has gain at the resonant frequency of the resonator that is larger than the feedback loop losses and the phase of the feedback loop satisfies steady state oscillation conditions. The RF power from the amplifier is coupled to the output coupling element **120** by the input coupling element. The output coupling element couples the RF energy to the bulb resulting in ionization of the inert gas followed by vaporization of the light emitter which then results in light emission from the bulb. Of course, there can be other variations, modifications, and alternatives.

FIG. **15**A illustrates a lamp similar to FIG. **14** except that the feedback coupling element has been eliminated. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications. Instead the RF source is provided by an oscillator **205** and an RF amplifier **210** with the output of the oscillator connected to the input **212** of the RF amplifier **210** and the output of the amplifier **211** is conductively connected with the input coupling element **630** through an RF connector **611**. The input coupling element delivers RF power to the output coupling element **120** which then couples it to the gas filled vessel **130**. This illustration is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

FIG. **15**B is a perspective view of the lamp shown in FIG. **15**A with an added reflector **670**. The luminous output from the bulb **130** is collected and directed by an external reflector **670**, which is either electrically conductive or if it is made from a dielectric material has an electrically conductive backing, and which is attached to and in electrical contact with the lamp body **600**. Reflector **670** is depicted as parabolic in shape with bulb **130** positioned near its focus. Those of ordinary skill in the art will recognize that a wide variety of possible reflector shapes can be designed to satisfy beam direction and distribution requirements. In a specific embodiment, the shapes can be conical, convex, concave, trapezoidal, pyramidal, or any combination of these, and the like. This illustration is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

FIG. **16**A is a cross-sectional perspective view of the lamp in FIG. **15**B without the RF source and the reflector. The input coupling element **630** is shown connected to the top surface **631** of the conductive lamp body of the compact air resonator/waveguide **600**. In this embodiment the integrated bulb/output coupling element assembly **120** is shown (unassembled) with a tapped screw bottom that can screw into the bottom of the conductive lamp body **605**. In this case the output coupling element is made from a solid conductor but it is possible to make it from a dielectric material with an electrically conductive layer. Since there are no electric fields inside the dielectric material the RF losses of the dielectric support structure used is not important. Other attachment methods, such as using set screws, are possible for connecting the output coupling element to the lamp body. This illustration is merely an example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

FIG. **16**B is similar to FIG. **16**A but in this case the output coupling element **120** is screwed into the bottom of the conductive lamp body **605**. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications. The gap **140** between the output coupling element **120** and the lamp body **650** as well as the length and the diameter of the output coupling element **120** are important in determining the resonant frequency of the air resonator/waveguide.

FIGS. **17**A, **17**B, **17**C, and **17**D illustrate some possible variations in the design of the compact air resonator/waveguide to achieve the same resonant frequency. Numerous other variations are possible giving the designer flexibility in the design of the compact air resonator/waveguide. By adjusting the length of the output coupling element **120**, the length of the top section of the lamp body **650** versus the size of the bottom section **625** as shown in FIG. **17**B it is possible to achieve the same resonant frequency as the air resonator/waveguide shown in FIG. **17**A. Another possibility is to change the air gap **140** between the top section **650** and the output coupling element **120** as shown in FIG. **17**C but use a shorter top section **650** to achieve the same resonant frequency. In FIG. **17**D part of the top section **650** of the air resonator is tapered to allow more gradual transition from the bottom section **625** to the top section. Many other variations are possible including changing the diameter of the output coupling element **120** or changing the dimensions of the bottom section **625** to change the resonant frequency of the air resonator/waveguide. These illustrations are merely some examples, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

FIG. **18** shows another embodiment of the present invention in which a dielectric sleeve **150** is inserted around the output coupling element **120**. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications. The dielectric sleeve increases the capacitance in the gap **140** between the output coupling element **120** and the top section of the lamp body **650** resulting in lowering the resonant frequency of the resonator/waveguide. The dielectric sleeve can be made from a material such as quartz but other materials are possible. One of ordinary skill in the art would recognize other variations, modifications, and alternatives.

FIG. **19** is similar to FIG. **15**B showing an embodiment of the compact air resonator/waveguide without the reflector and the RF source. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications. The maximum dimension (dimensions C, D, and E in the Figure) of the compact air resonator/waveguide of any one dimension in a three coordinate system (XYZ) is less than one half of the free space wavelength of the resonant frequency of the fundamental mode of the air resonator/waveguide. As shown in a specific embodiment, the present invention provides a plasma lamp apparatus. The apparatus includes a gas filled vessel having a transparent or translucent body configured by an inner region and an outer surface region, a cavity being defined within the inner region. The apparatus also has an air resonator region configured within a vicinity of the gas filled vessel. In a specific embodiment, the air resonator region has a maximum dimension of less than one half of a free space wavelength of a fundamental resonant frequency of the air resonator region. The apparatus has an rf source configured to generate a resonant frequency of 2.5 GHz and less and coupled to the air resonator region. Of course, there can be other variations, modifications, and alternatives.

In alternative specific embodiments as shown, the present invention provides an alternative plasma lamp apparatus. The apparatus has a waveguide body having a maximum dimension of less than one half of a free space wavelength of a resonant frequency. The maximum dimension is selected from any one dimension in a three coordinate system. Of course, there can be other variations, modifications, and alternatives.

FIG. **20** shows the temperature profile of the surface of the gas filled vessel (in this case a quartz bulb) as a function of the distance above the output coupling element. The bulb as well as part of the top portion of the resonator/waveguide from FIG. **13** is shown on the right hand side of FIG. **20**. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications. In this case the bulb is operated in the vertical direction. The maximum temperature of around 852° C. occurs approximately at two thirds of the length of the bulb above the end of the output coupling element. The lowest temperature of around 783° C. occurs just slightly above the end of the output coupling element which in this case is also in close proximity to the maximum Electric field region inside the bulb. Depending on the orientation of the bulb, design of the resonator (including dimensions of the output coupling element and materials used to make it) as well as the shape and size of the bulb, as well as other parameters, one can change the temperature profile of the surface of the bulb. Of course, there can be other variations, modifications, and alternatives.

In still an alternative embodiment as shown, the present invention provides still an alternative plasma lamp apparatus. The apparatus has a gas filled vessel having a transparent or translucent body configured by an inner region and an outer surface region and a cavity being defined within the inner region. In a specific embodiment, the gas filled vessel has a first end portion and a second end portion. The apparatus has a maximum temperature profile spatially disposed within a center region of the gas filled vessel in a preferred embodiment, although the maximum may be slightly offset in some cases. In a specific embodiment, the center region is between the first end portion and the second end portion. In a preferred embodiment, the maximum temperature profile is within a vicinity of the outer surface region substantially free from interference with a solid resonator body region. Of course, there can be other variations, modifications, and alternatives.

FIG. **21**A shows a simplified cross sectional view of a gas filled vessel **130** in a conventional dielectric resonator **500** and FIG. **21**B shows a simplified cross sectional view of a gas filled vessel **130** in an embodiment **600** of the present invention. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications. As one can see in FIG. **22**A in the case of the conventional dielectric resonator the majority of the light from the arc of the bulb (**135**) will first hit the opaque walls of the dielectric resonator since most of the bulb is inside the dielectric resonator and the light gets reflected back into the bulb. Part of this reflected light gets absorbed by the arc and then re-emitted. The light continues to bounce back and forth until it is emitted (**145**) from the top surface of the bulb. Typically a reflective coating or material is used to surround the bulb (except for the top surface) to reduce reflective losses but nevertheless some of the reflected light is lost in the process. In the case of the compact air resonator/waveguide **600** shown in FIG. **21**B the majority of the emitted light **135** from the arc of the bulb pass through the walls of the transparent or translucent gas filled vessel without being reflected back into the bulb. The light emitted from the surface of the bulb **145** is emitted from most of the surface of the bulb without having gone through multiple reflections. Of course, there can be other variations, modifications, and alternatives.

As shown, the present invention provides a plasma lamp apparatus according to one or more embodiments. The apparatus comprises a gas filled vessel having a transparent or translucent body configured by an inner region and an outer surface region, a cavity being defined within the inner region and an rf source coupled to the gas filled vessel to cause electromagnetic radiation to pass through at least 50% of the outer surface region without reflection back into the inner region of the gas filled vessel. Moreover, the present invention provides a method for emitting electromagnetic radiation from a plasma lamp apparatus. The method includes generating electromagnetic radiation from within an inner region of a gas filled vessel using at least one or more rf sources configured to provide rf energy to the gas filled vessel and transmitting a portion of the electromagnetic radiation from the inner region of the gas filled vessel through at least 50% of an outer surface region of the gas filled vessel without substantial refection back into the inner region of the gas filled vessel. Of course, there can be other variations, modifications, and alternatives.

FIG. **22**A shows a perspective view of a conventional dielectric resonator **500** and FIG. **23**B shows a perspective view of an embodiment of the present apparatus **600** according to an embodiment of the present invention. From the perspective of a viewer **900** in FIG. **22**A looking at the arc of the bulb **115** only the top portion of the arc is visible (top dashed line of sight **915**). The other two line of sights (two dashed lines marked with an X **920**) to the middle and bottom of the arc are blocked by the opaque dielectric resonator. If the viewer moves around 360 degrees in a circle around the dielectric resonator (circular dashed line **950**) still only the top of the arc is visible to the observer. In the case of the compact air resonator/waveguide **600** shown in FIG. **22**B a viewer **900** has a clear line of sight to the bottom, middle, and top of the arc of the bulb **115** (three dashed lines **925**). In addition if the viewer moves around 360 degrees in a circle around the compact air resonator (circular dashed line **950**), the viewer will have a clear view of the arc of the bulb. Of course, there can be other variations, modifications, and alternatives.

The present invention provides an electrode-less plasma lamp apparatus in yet an alternative embodiment as shown. The apparatus has a gas filled vessel having transparent or translucent body configured by an inner region and an outer surface region, a cavity being defined within the inner region, which is free from one or more electrode structures. The apparatus has a support body configured to mate with the gas filled vessel and an arc feature caused by electromagnetic radiation and having a first end and a second end provided spatially within the inner region. In a preferred embodiment, at least 50% of the arc feature is exposed when viewed from any spatial position within 360 Degrees and greater of an imaginary line normal to a center portion between the first end and the second end of the arc feature. In one or more embodiments, the arc feature is provided within the spatial region between a first end and a second end of the inner region. Of course, there can be other variations, modifications, and alternatives.

In yet other embodiments, the present invention provides an electrode-less plasma lamp apparatus. The apparatus has a gas filled vessel having transparent or translucent body configured by an inner region and an outer surface region and a cavity being defined within the inner region, which is free from one or more electrode structures. The apparatus also has a maximum electric field region configured within a portion of the inner region of the gas filled vessel. In a specific embodiment, the maximum electric field region is exposed from an exterior region of the gas filled vessel when viewed from any spatial position within 360 Degrees and greater of an imaginary line normal to a center portion of the gas filled vessel.

FIG. **23**A shows a luminaire using a metal halide lamp **730** with electrodes inside the bulb **731**. A secondary glass/quartz envelope **735** surrounds the gas filled vessel **731**. A ballast **750** is used to operate the lamp. In this case since the arc of the bulb is large it is difficult to design compact low-cost reflector **700** that can efficiently collect all the light that the bulb generates. In the case of a luminaire designed using one of the embodiments of this invention, FIG. **23**B, the gas filled vessel (bulb) **130** is compact so it can be treated as a point light source in designing reflectors. As a result from compact and efficient reflectors **725** can be designed to collect all the light that the bulb generates. In this case an RF driver/ballast **770** is used to operate the lamp. In one or more embodiments, the invention preferably provides a single source plasma lamp apparatus. The apparatus has a single point source configured to be electrode-less and having a maximum dimension of 3 centimeters and less and an emission of electromagnetic radiation having at least 20,000 lumens emitted from the single point source. As shown, the present apparatus eliminates the use of arrays of lamps and other complex cumbersome designs. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications.

FIG. **24** shows an example of the spectrum emitted from one of the embodiments of this invention. This diagram is merely example, which should not unduly limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications. The spectrum has emission in the visible, ultraviolet, and infrared region of the spectrum. By changing the light emitters inside the gas filled vessel one can change the spectral characteristics of the emitted light. The device is also provided in one or more embodiments. The device comprises an rf source; an electromagnetic resonator structure coupled to at least one rf coupling element configured to introduce rf energy into the electromagnetic resonator structure and a bulb comprising a fill material. The bulb is coupled to the electromagnetic resonator structure to emit electro-magnetic energy from a spectrum of at least ultra-violet, visible, or infrared; and an exposed region of the bulb protruding outside of the electromagnetic resonator structure to cause a substantial portion of the electromagnetic radiation to be emitted from exterior surfaces of the bulb without reflection from the electromagnetic resonator structure. In one or more embodiments, the spectrum may include combinations of the above as well as other regions. Of course, there can be various combinations, alternatives, and variations.

While the above is a full description of the specific embodiments, various modifications, alternative constructions and equivalents may be used. Therefore, the above description and illustrations should not be taken as limiting the scope of the present invention which is defined by the appended claims.

What is claimed is:

1. A method for forming a plasma lamp apparatus, the method comprising: providing an arc tube structure; subjecting one portion of the arc tube structure to a thermal treatment process; and coupling a stem structure to the portion of the arc tube structure, wherein the stem structure is configured to cause thermal energy to be transferred from the arc structure to the stem structure.

2. The method of claim **1** further comprising evacuating an inner region of the arc tube structure.

3. The method of claim **2** further comprising transferring a fill material to the inner region.

4. The method of claim **3** wherein the fill material comprises liquid mercury.

5. The method of claim **3** wherein the fill material comprises selectively metered liquid mercury.

6. The method of claim **3** wherein the fill material is configured to discharge substantially white light along a visible range representative of a black body source and providing at least 120 lumens per watt.

7. The method of claim **3** wherein the fill material comprises thulium bromide ranging from about one third to about four thirds mg/cm^3.

8. The method of claim 3 wherein the fill material comprises indium bromide ranging from about one third to about four thirds mg/cm^3.

9. The method of claim 3 wherein the fill material comprises mercury ranging from about 10 to about 13.333 mg/cm^3.

10. The method of claim 3 wherein the fill material comprises dysprosium bromide ranging from about one third to about four thirds mg/cm^3.

11. The method of claim 3 wherein the fill material comprises a determined amount of dysprosium bromide to cause a selected color temperature.

12. The method of claim 11 wherein the selected color temperature ranges from about 4000 to about 5000 Kelvin.

13. The method of claim 3 wherein the fill material comprises about 200 Torr of Argon.

14. The method of claim 2 further comprising transferring argon comprising krypton 85 to the inner region.

15. The method of claim 2 further comprising transferring a starting gas(es) into the inner region.

16. The method of claim 1 further comprising metering liquid mercury and maintaining the liquid mercury in a liquid state substantially free from a vapor phase.

17. The method of claim 1 further comprising metering liquid mercury using a syringe device.

18. The method of claim 1 further comprising transferring liquid mercury as a single slug structure from a source to an inner region of the arc tube structure.

19. The method of claim 1 wherein the thermal process is provided by a flame at a temperature ranging from about 1500 to 2500 Degrees Celsius.

20. The method of claim 1 wherein the stem structure is configured to have sufficient support strength.

21. The method of claim 1 wherein the stem structure is fittingly coupled to a base region.

22. The method of claim 1 wherein the stem structure is fitted into a metal structure.

23. The method of claim 1 wherein the stem structure is collinear with the arc tube structure.

24. The method of claim 1 further comprising checking he pressure of the arc tube structure to determine whether the arc tube structure is leaking.

25. The method of claim 1 further comprising determining if the arc tube structure is hermetically sealed.

26. A method for forming a plasma lamp apparatus, the method comprising:

providing an arc tube structure;

subjecting one portion of the arc tube structure to a thermal treatment process;

coupling a stem structure to the portion of the arc tube structure, and

forming an air resonator region configured within a vicinity of the arc tube structure, the air resonator region having a maximum dimension of less than one half of a free space wavelength of a fundamental resonant frequency of the air resonator region.

27. A method for forming a plasma lamp apparatus, the method comprising: providing an arc tube structure having an arc tube region and an open region; transferring one or more materials into the arc tube structure through the open region; subjecting the open region to a thermal process to form a pinched region and seal the open region; and forming a stem structure from a region within a vicinity of the pinched region, the stem structure having a stem region, wherein the stem structure is fitted into a metal structure.

28. The method of claim 27 further comprising evacuating an inner region of the arc tube structure.

29. The method of claim 28 further comprising transferring a fill material to the inner region.

30. The method of claim 28 wherein the fill material comprises liquid mercury.

31. The method of claim 28 wherein the fill material comprises selectively metered liquid mercury.

32. The method of claim 28 wherein the fill material is configured to discharge substantially white light along a visible range representative of a black body source and providing at least 120 lumens per watt.

33. The method of claim 28 wherein the fill material comprises thulium bromide ranging from about one third to about four thirds mg/cm^3.

34. The method of claim 28 wherein the fill material comprises indium bromide ranging from about one third to about four thirds mg/cm^3.

35. The method of claim 28 wherein the fill material comprises mercury ranging from about 10 to about 13.333 mg/cm^3.

36. The method of claim 28 wherein the fill material comprises dysprosium bromide ranging from about one third to about four thirds mg/cm^3.

37. The method of claim 28 wherein the fill material comprises a determined amount of dysprosium bromide to cause a selected color temperature.

38. The method of claim 37 wherein the selected color temperature ranges from about 4000 to about 5000 Kelvin.

39. The method of claim 28 wherein the-fill material comprises about 200 Torr of Argon.

40. The method of claim 27 further comprising transferring argon comprising krypton 85 to the inner region.

41. The method of claim 27 further comprising transferring a starting gas(es) into the inner region and thereafter subjecting the open region to the thermal process.

42. The method of claim 27 further comprising metering liquid mercury and maintaining the liquid mercury in a liquid state substantially free from a vapor phase.

43. The method of claim 27 further comprising metering liquid mercury using a syringe device.

44. The method of claim 27 further comprising transferring liquid mercury as a single slug structure from a source to an inner region of the arc tube structure.

45. The method of claim 27 wherein the thermal process comprises subjecting the vicinity to a flame to cause formation of the pinched region.

46. The method of claim 27 wherein the thermal process is characterized by a temperature ranging from about 1500 to 2500 Degrees Celsius.

47. The method of claim 27 wherein the thermal process is provided by a flame having a temperature ranging from about 1500 to 2500 Degrees Celsius.

48. The method of claim 27 wherein the arc tube region comprises a first diameter and the stem region comprises a second diameter, the ratio between the first diameter and the second diameter being greater than four.

49. The method of claim 27 wherein the stem structure is configured to cause thermal energy to be transferred from the arc structure to the stem structure.

50. The method of claim 27 wherein the stem structure is configured to have sufficient support strength.

51. The method of claim 27 wherein the stem structure is fittingly coupled to a base region.

52. The method of claim 27 wherein the stem structure is collinear with the arc tube structure.

53. The method of claim 27 further comprising checking the pressure of the arc tube structure to determine whether the arc tube structure is leaking.

54. The method of claim **27** further comprising determining if the arc tube structure is hermetically sealed.

55. The method of claim **27** further comprising an air resonator region configured within a vicinity of the arc tube structure, the air resonator region having a maximum dimension of less than one half of a free space wavelength of a fundamental resonant frequency of the air resonator region.

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